

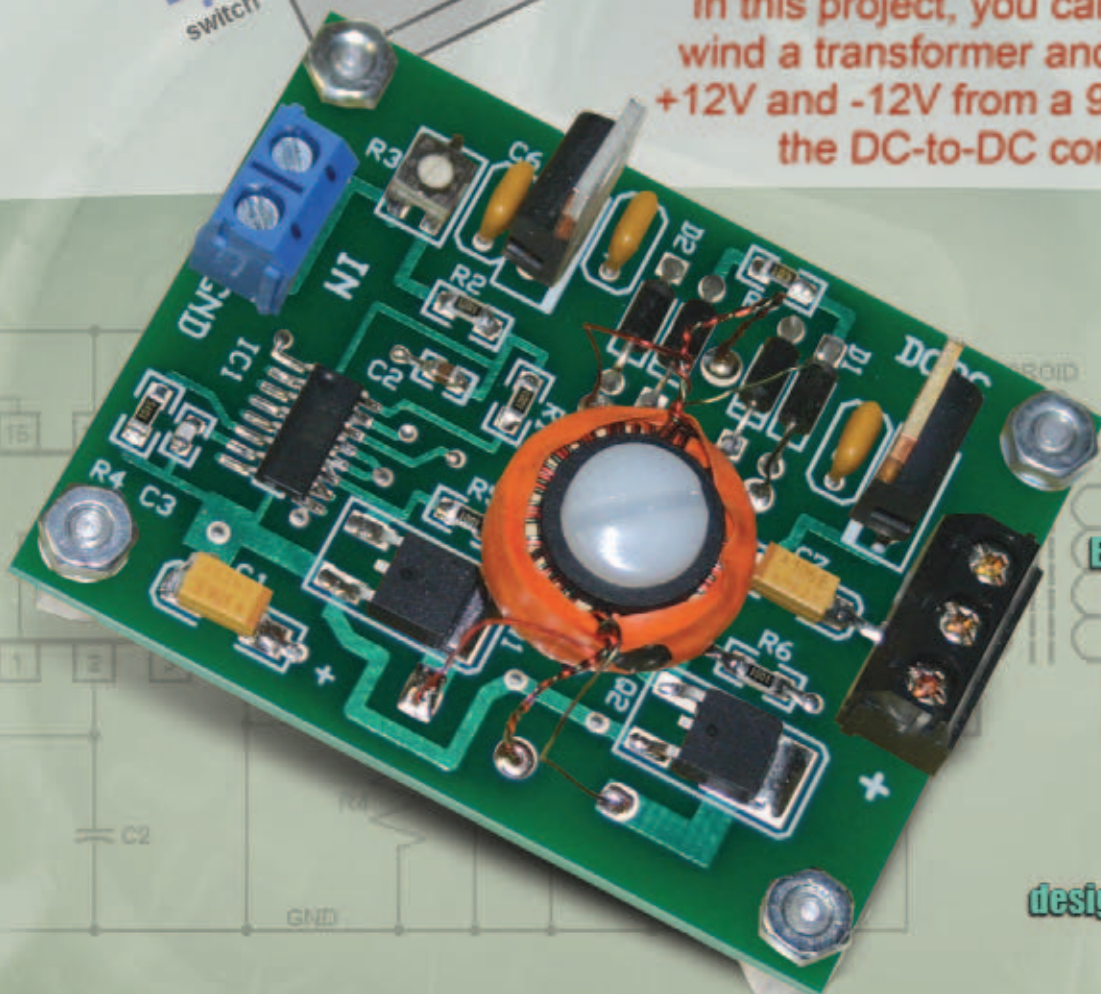
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◆ **Inductive Proximity Sensors**  
Build this series resonant circuit using a Propeller Demo Board to detect metal objects

◆ **Making The DEFCON 16 Badge**  
Get an inside look at the design process and problems faced while making this unique device

◆ **The Design Cycle**  
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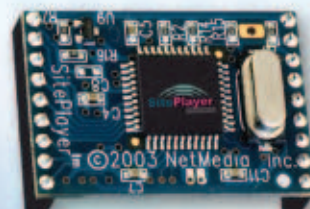
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## 12 TechKnowledge 2009

Topics covered include a dual-screen laptop, phone watch, motor sets RPM record, plus more.

## 16 Stamp Applications

*Putting the Spotlight on BASIC Stamp Projects, Hints & Tips*

Creating Time-Lapse Video.

## 28 Q & A

### *Reader Questions Answered Here*

Measuring energy use, more on oscillators,  
flat panel TVs, plus more.

## 60 The Design Cycle

*Advanced Techniques for Design Engineers*  
Demystifying USB to Serial.

## 67 Smiley's Workshop

*An AVR C Programming Series*  
Interrupts, I/O Registers, and the  
Butterfly Joystick.

## 71 Personal Robotics

*Understanding, Designing & Constructing Robots*

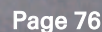
Robotics on a Budget.

## 76 Near Space

*Approaching the Final Frontier*  
BalloonSat Minis.

## 82 Getting Started With PICs

*The Latest in Programming Microcontrollers*  
SPI Communication.



## 36 Inductive Proximity Sensors

A series resonant circuit built on a Propeller demo board is utilized in this build to detect the proximity of metallic objects. ■ *By Beau Schwabe*

●●●● Advanced Level

## 40 Makin' MIDI with mistralXG

This time, we look under the hood of last month's design to see how the mistralXG hardware and software work together. ■ *By Steve Russell*

●●●● Advanced Level

## 46 Wind Your Own Transformers and Build a DC-to-DC Converter

Use this board as a platform for your switch-mode projects and experiment with winding transformers.

■ *By Jim Stewart*

●●●● Advanced Level

## 54 Making the DEFCON 16 Badge

Joe highlights his design process and the problems he encountered during the creation of his most recent DEFCON badge. ■ *By Joe Grand*

08	DEVELOPING PERSPECTIVES	88	NV WEBSTORE
34	NEW PRODUCTS	92	CLASSIFIEDS
35	SHOWCASE	94	TECH FORUM
87	ELECTRO-NET	97	AD INDEX



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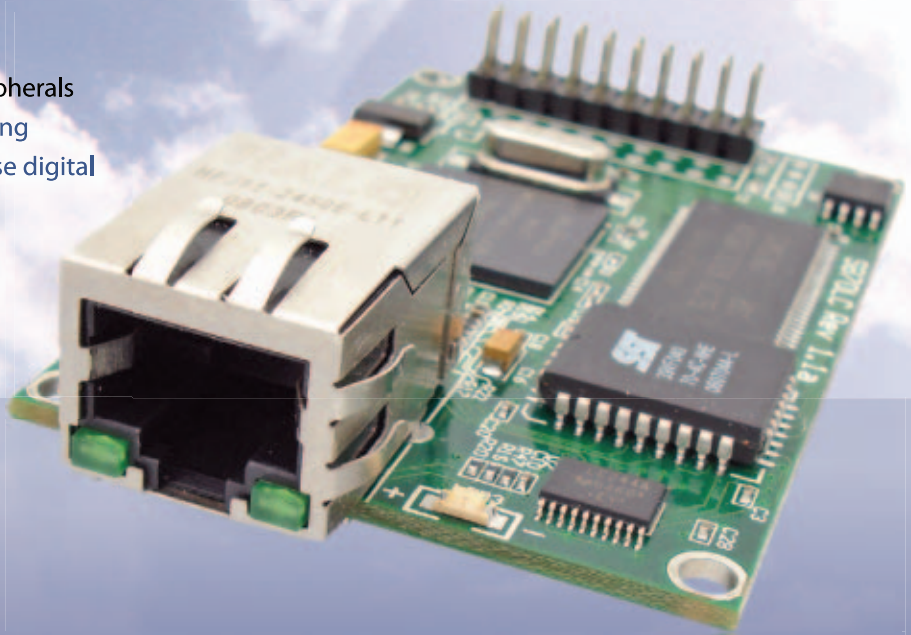
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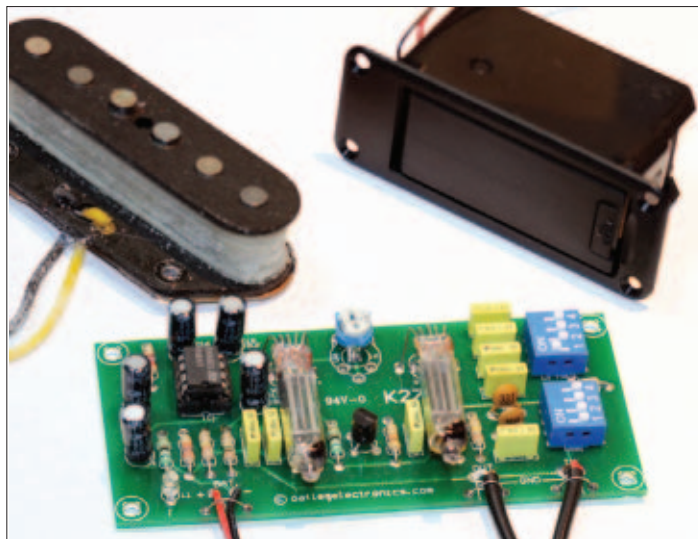
by Bryan Bergeron, Editor

# DEVELOPING PERSPECTIVES

## Kit Building

**A**s a young ham radio enthusiast, I assembled my first operating station by tearing down and reassembling broken TVs and radios. After months of saving from several odd jobs, I was able to step up to a 'real' rig — a DIY crystal-controlled CW transmitter from the now defunct Heathkit Corporation. Over the years, I eventually acquired an amplifier, digital multimeter, SWR meter, PLL-based transceiver, and other test and operating equipment kits from the company. The equivalent of paint-by-numbers, the various kits were not only affordable, but easy to repair and modify. Given the well-written documentation and large user community, I was virtually guaranteed of success, and there was no scrounging for hard-to-find, expensive parts.

Heathkit eventually lost the niche for low-end communications and test equipment to less expensive, more compact, and more functional fully-assembled equipment from overseas. Today, it's still the case that



**K-270 preamp, guitar pickup, and 9V battery compartment.**

pre-assembled, imported equipment is often the most affordable option.

However, for electronics enthusiasts, it's not only the final product, but the process of designing and/or building circuits that counts. Economics still matter, but most of us are willing to pay a reasonable premium for the opportunity to assemble a circuit ourselves. In fact, what makes a kit so attractive these days is the relative cost savings over assembling a circuit piecemeal; \$5 for a blank perf-board; \$2 for a battery clip; \$1.50 for a voltage regulator chip. Pretty soon, the cost of even the most modest circuit can get out of hand. Hence, the renewed popularity of kits.

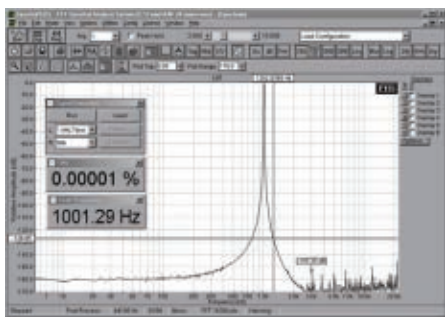
My latest kit project is a hybrid preamp, the K-270 from Oatley Electronics ([www.oatleyelectronics.com](http://www.oatleyelectronics.com)). At \$20, the kit (see photo) makes an affordable, high-quality guitar amplifier that provides real 'tube sound' that even the best all solid-state preamps can only approximate. As points of comparison, I could have bought a self-contained, solid-state preamp with a nice enclosure for about \$35, or copied the K-270's circuit design and ordered the parts from Mouser for about \$50. I went with the kit, and used a guitar body for the main enclosure. Go ahead and make your own comparison — the parts list and schematic are available on the Oatley Electronics website.

As you can see in the photo, the hybrid preamp features two JAN6418 sub-miniature pentodes. The pentodes are cascaded in common cathode configuration, each with 1.2V @ 5 mA filaments, followed by a MOSFET buffer. A 5V regular accepts 9 VDC battery input. In addition, an input high-pass and low-pass filter composed

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of switched capacitors enables you to modify the basic 20 Hz - 30 kHz response. Maximum gain is about 100, with a maximum draw of about 11 mA at 9V. The diminutive preamp is just a little larger than a magnetic guitar pickup.

Instead of designing an amplifier from scratch, I invested my time in integrating the amplifier into my electric guitar. After routing my solid-body traveler guitar body with

two cavities — one for the amplifier and one for the 9V battery holder — I coated each cavity with conductive paint. Next, I mounted the board and battery holder, and added an on-off switch in series with the 9V supply.

As with most well-designed and documented kits, the preamp lends itself to modification. I couldn't resist modifying the input high- and low-pass filter circuits and adjusting the tube plate voltage to get more of a

vintage sound from the preamp.

The take-away is that kits are an affordable, low-risk, fun way to learn about and experience electronics. Several kit companies regularly advertise in *Nuts & Volts*, and we offer kits from some of our authors in the *Nuts & Volts* website.

If you're new to kits or simply haven't put one together in a while, this is a great time to try your hand at one. **NV**

## New Soldering Tip Recycling Program



**C**ooper Tools has a new recycling program for worn-out soldering tips. By recycling the copper and iron from used tips, end-users will be able to make a solid contribution towards helping the environment and preserving its natural resources. Plus, for every two pounds of worn-out tips turned in for recycling, Cooper Tools will offer a \$75 voucher to be used towards the purchase of new Weller® tips. Any brand of soldering or desoldering tip is eligible for this recycling program, including tips from any other manufacturer.

A free tip recycling/shipping box is available from Cooper Tools to make collecting old tips easy and convenient. The box can be shipped to Cooper Tools in return for the \$75 Weller voucher once it's full or reaches two pounds in weight. To request a tip recycling box or to get information about any Weller product, contact a participating Weller distributor or call Cooper Tools at (866) 498-0484. You can also email Weller Technical Services at [weller-na@cooperindustries.com](mailto:weller-na@cooperindustries.com).

"Cooper Tools is committed to supporting actions that help protect our environment," said Glenn Schindo, director of marketing and sales for Weller. "This new program gives our customers the opportunity to conserve natural resources while decreasing their operational costs associated with purchasing soldering tips."

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Published Monthly By  
**T & L Publications, Inc.**  
430 Princeland Ct.

Corona, CA 92879-1300

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### Subscriptions

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Outside US 1-818-487-4545

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North Hollywood, CA 91615

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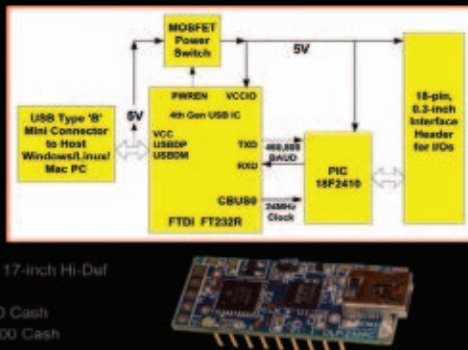
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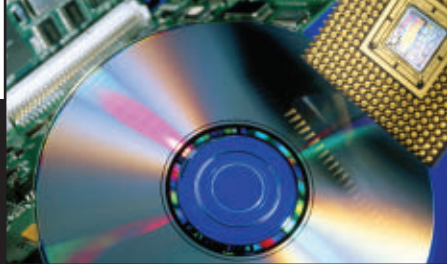
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■ BY JEFF ECKERT

## ADVANCED TECHNOLOGY

### HIGH-ALTITUDE, LONG-DURATION INSTRUMENT PLATFORM



PHOTO COURTESY OF ROBYN WASERMAN, NATIONAL SCIENCE FOUNDATION.

■ A super pressure balloon is inflated at a facility near McMurdo Station, Antarctica.

Let's say you're a scientist at a university or atmospheric research organization, and you need to make some high-altitude measurements. One option is to strap your instrument cluster to an Atlas or Titan launch vehicle and put it into a geosynchronous orbit. If the package weighs, say, 500 lbs, you're looking at \$5-6.5 million to get it there, so you'll need a fat wallet. However, there is a cheaper alternative, as recently demonstrated in a joint venture between the National Science Foundation (NSF, [www.nsf.gov](http://www.nsf.gov)) and NASA ([www.nasa.gov](http://www.nasa.gov)). Late last year, they conducted a flight test of a new "super pressure balloon" prototype — an improved long duration balloon (LDB) designed to carry large scientific experimental gear to the edge of space for 100 days or more.

The purpose of this flight was to test the durability and functionality of the balloon's unusual pumpkin-shaped design and its novel material — a lightweight co-extruded polyethylene film about the thickness of ordinary plastic food wrap. (In a super pressure balloon, the pressure [rather than the volume] of the lifting gas changes with diurnal heating and

cooling, providing constant buoyancy.)

According to senior scientist W. Vernon Jones, "While the team has a ways to go in scaling up the pumpkin balloon to be able to lift a one-ton instrument to a float altitude of 110,000 feet, the team has demonstrated they are on the right path." The prototype has a capacity of seven million ft<sup>3</sup>, but the full-scale model will be expanded to 22 million ft<sup>3</sup>.

No cost information was provided, but various sources peg the bill of an LDB at up to \$110,000 and enough helium to fill it at \$10,000. Adding some overhead for launching and recovering the vehicle, ground transportation, etc., you're probably looking at \$250,000 or so.

Several older designs of LDBs are already in operation for things like cosmic and gamma ray studies, infrared astronomy, magnetospherics, etc. If you are interested in tracking their movements, log onto the Columbia Scientific Balloon Facility at [www.csbf.nasa.gov/antarctica/ice0809.htm](http://www.csbf.nasa.gov/antarctica/ice0809.htm).

### MOTOR SETS RPM RECORD

Yeah, it's just an electric motor, but up to now, the fastest one you could get turned about 250,000 RPM. However, the Department of Power Electronics at the Swiss Federal Institute of Technology Zürich (ETH Zürich,

[www.ethz.ch](http://www.ethz.ch)) has designed a device (prototype built by partner ATE GmbH) that breaks the one million RPM barrier, which is pretty amazing when you think about it.

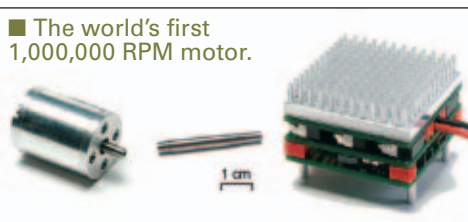
The breakthrough involved jumping a few hurdles. For one thing, the rotor construction required a special titanium shell to withstand the extreme centrifugal forces involved. The ball bearings (provided by myonic GmbH) had to be optimized for such high speeds. And ETH had to design a special low-loss stator that uses ultra-thin copper wire for the windings, which are inserted in a cylinder made of a specially developed type of iron. Finally, the machine is fed by electronics that had to be specifically designed for such speeds.

The result is a spin-off company — Celeroton ([www.celeroton.com](http://www.celeroton.com)) — which has put the motors into production and is "set to become a supplier for manufacturers of, for example, fast-spinning drills or milling machines. The trend towards increasingly smaller cell phones and other electrical appliances means that increasingly smaller holes have to be drilled for the electronics. This is only possible using a drive system that boasts a high rotational speed." Potential applications include microcompressors, micromachining in the semiconductor and PCB industries, fuel cell production, aircraft part manufacturing, etc.

## COMPUTERS AND NETWORKING

### DUAL-SCREEN LAPTOP INTRODUCED

Those of us who are accustomed to working with dual monitors can enthusiastically recommend the practice, which allows you to use one screen for the main item of interest and the other for toolboxes, IM



■ The world's first 1,000,000 RPM motor.



### ■ The Lenovo ThinkPad W700ds.

windows, email, and whatever. Until now, this feature has been readily available only with desktop boxes. But in January, Lenovo ([www.lenovo.com/us/en/](http://www.lenovo.com/us/en/)) introduced a dual-screen ThinkPad — the W700ds — which it prefers to call a "mobile workstation."

It is fitted with a 17 in LCD main monitor plus a 10.6 in slide-out secondary one. The latter can be adjusted at an angle of up to 30° for easier viewing. You also get a choice of Intel mobile quad core processors and a NVIDIA® Quadro FX mobile graphics CPU with up to 128 cores, optional dual hard drives with RAID configurations and/or solid-state storage, and up to 8 GB of DDR3 memory. This makes possible a maximum of 960 GB of storage. As a Lenovo representative noted, "This is the nitro-burning drag racer of ThinkPads."

The main negative features appear to be the machine's price (ranging from \$3,069 for the basic unit to well over \$8,000 with a heavy helping of the bells, whistles, and extended warranties), and weight (11 lb [5 kg]). The latter may explain why the company doesn't call it a laptop.

### WITH FRIENDS LIKE THIS ...

**B**urger King — already known for its often bewildering marketing methods — last year instituted the Whopper® Sacrifice website ([www.whoppersacrifice.com](http://www.whoppersacrifice.com)), aimed at Facebook users. The concept is simple. If you are willing to delete 10 of your Facebook friends, you can download a small application, give them the boot, and subsequently receive a coupon for a free Whopper.

Alas, you are now stuck with your Facemates, as well as the empty stomach. BK decided to shut down the program after people traded away

233,906 of their friends (apparently, at least one applicant couldn't count to 10). The stampede on free burgers isn't too surprising, given that Facebook has something like 150 million users, most of whom are in the fast-food-gobbling age group of 18 to 34 year olds.

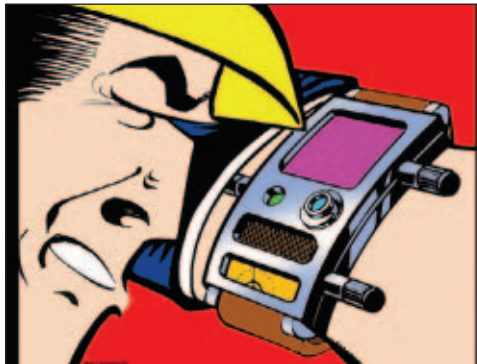
But don't be too disappointed. A Whopper with cheese contains 770 calories, 48 g of fat (16 g saturated), 100 mg of cholesterol, and 1,450 mg of salt. At least your no-good friends aren't likely to give you a coronary.

The website is still up and running, and if you have been sacrificed and aren't happy about it, you can still send your ex-friend an Angry-Gram that includes a screaming animated sandwich.

## CIRCUITS AND DEVICES

### PHONE WATCH AND MORE

**T**he concept dates back to 1946, when cartoon police detective



■ LG's Touch Watch Phone brings Dick Tracy's wrist radio to the real world.



Dick Tracy and other members of the force were issued two-way wrist radios. Now, 63 years later, LG Electronics ([www.lge.com](http://www.lge.com)) has taken it a step further with the LG-GD910 Touch Watch Phone. It's the commercial version of a prototype introduced about a year ago, upgraded to include a touchscreen interface, 3G capabilities, and video calling.

According to LG, it's the first watch phone in the world to feature 7.2 Mbps 3G HSDPA compatibility, which enables high-speed data transmission and video phone calls using its built-in camera. It also has voice recognition capabilities (with or without a Bluetooth headset), a text-to-speech feature, and a built-in speaker for playing music files. The device will go on sale in Europe sometime this year but — sorry to inform you — no release date has been revealed for the USA.

### WORSE SPEAKERS/ BETTER SOUND

**I**n the old days, a reliable rule of thumb was that the heavier the magnet, the better a speaker's sound quality. The employment of light, rare earth magnets has more or less smacked that thumb with a hammer, but it remains difficult to get decent sound from the crappy little \$2 transducers that come with low-end audio systems. Addressing the problem is the Sound Terminal™ STA339BWS chip.

Recently introduced by STMicroelectronics ([www.st.com](http://www.st.com)), it merges the company's audio processing and class-D power amplifier ICs into a single package and includes multiband dynamic range compression (DRC). DRC "uses the latest sound-processing algorithms to enhance the performance of low-cost speakers, and also prevents large bass signals from causing vibrations and damaging small speaker units."

The chip also incorporates a seven-band equalizer and provides continuous audio streaming when changing channels or audio sources. Output is configurable to provide

2 x 20W stereo into 8 or 2.1 channels at 2 x 10W plus 20W, allowing it to serve different products. The IC is pin-compatible with existing Sound Terminal ICs for flat-panel TVs, so it should be easy to incorporate in next-generation products. Available in a PowerSSO-36 package, it runs \$2.50 each in production quantities. **NV**

■ The STA339BWS is aimed at compact home audio equipment.



PHOTO COURTESY OF STMICROELECTRONICS.

## INDUSTRY AND THE PROFESSION

### THE FEUD CONTINUES

For a while, it looked like the altercation between Apple and a Mac clone maker was over, but Psystar has filed a revised version of its argument that Apple has abused copyright laws by tying its operating system to Apple hardware. Psystar buys legal copies of OS X and installs them on its Open Computer and OpenPro machines, which it claims is perfectly legal. And while it's true that Apple's end-user license agreement forbids installing the system on anything other than its own hardware, Psystar's view is that the license agreement runs counter to US law and the "first sale" doctrine.

The doctrine — which goes back to a 100 year old Supreme Court decision — allows the purchaser of any copyright work to sell or give it away without the copyright holder's permission. The case is scheduled to hit the trial stage in April, so stay tuned. In the meantime, it looks like you can still buy an Open with OS X (with 2.2 GHz dual core Pentium processor, 2 GB RAM, 320 GB drive) for \$554.99 or an OpenPro (3.16 GHz Core2Duo or 2.4 GHz Core2Quad, 2GB RAM, 750 GB drive) for \$1,154.99. Go to [www.psystar.com](http://www.psystar.com) if you dare.

## NEED A CONVERTER BOX? YOU LOSE!

In other news that will disappoint some owners of now-obsolete TV sets, the National Telecommunications and Information Administration ([www.ntia.doc.gov](http://www.ntia.doc.gov)) used up its \$1.3 billion of Congressional funding for the TV Converter Box Coupon Program even before analog programming was phased out as of February 17<sup>th</sup>. As of this writing, US residents applying for a digital TV converter box voucher will be put on a waiting list. It seems that 24 million households had applied for a total of 46 million of the \$40 coupons. Only 53 percent have been redeemed, with 13 million having passed the 90-day expiration date. But don't throw away the old Philco box just yet. According to acting NTIA Administrator Meredith Attwell Baker, the NTIA will work with Congress and the administration to "ensure everyone is prepared for the transition and no one is left in the dark."

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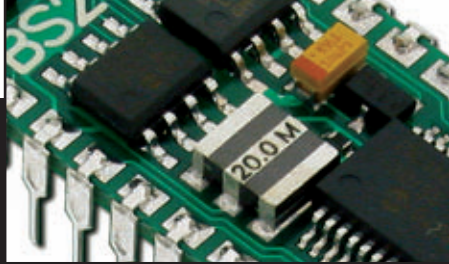
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# STAMP APPLICATIONS

PUTTING THE SPOTLIGHT ON BASIC STAMP PROJECTS, HINTS & TIPS

■ BY JON WILLIAMS

## CREATING TIME-LAPSE VIDEO

**FOR AS LONG AS I CAN REMEMBER**, my two favorite subjects have been movies and electronics, and I'm especially happy when I get the opportunity to combine the two. In the 80s, I saw an IMAX feature called "Chronos" that just blew me away; the entire movie was shot using time-lapse cinematography — it was breathtaking. I was so inspired by that movie that I built a 555 circuit to control my Super-8 camera in single-frame mode. This let me compress a four-hour drive from Los Angeles to Las Vegas into a three-minute (one reel) Super-8 movie. In the video age, time-lapse movies are not easily produced with a video camera, but as my friend (and VFX wizard) John demonstrated, one can easily create a time-lapse movie with a digital still camera and video editing software.

### MOVIES ARE ACTUALLY STILLS

When we go to the theater to see a "motion picture," what we're actually seeing is the projection of 24 still images every second; it is our eyes and brain that blend the images into what seems like smooth motion. It makes sense, then, that we can take any series of images and

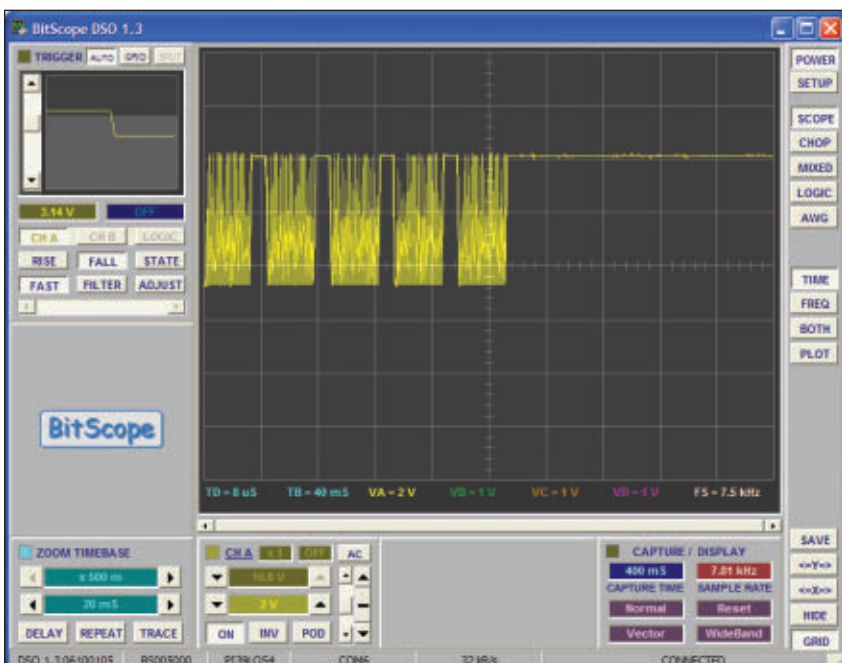
stitch them together to make a "movie." Of course we can, animators do this day in and day out to make cartoons. Video cameras are not set up (very well, anyway) to take single frame images like film cameras, so we have to take a different path: use a digital still camera.

When John showed me this trick, I actually laughed as it is so elegantly simple. Using a digital still camera to create a time-lapse movie is possible for two reasons: 1) The still

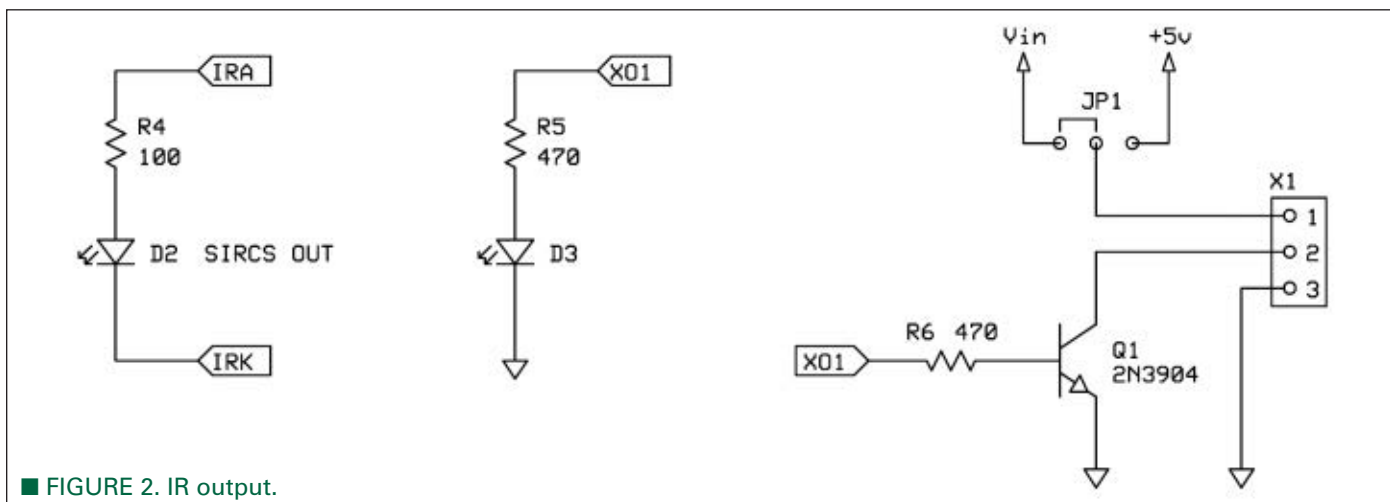
camera saves images as numbered files; and 2) Almost every video editing application has the ability to take a group of numbered still images and convert them to a video file. My Sony digital still camera conveniently has frame sizes that match standard and high-def video frame sizes; the only thing I have to do is trigger the camera at the desired interval.

Once I got hooked on this idea, I started doing a bit of research and guess what? I'm not the first to go down the path of creating a time-lapse controller with the SX. In the December 2007 issue, Joe DeMeyer created a very nice, fairly sophisticated intervalometer using the SX48, a DS1302 RTC, and a Parallax serial LCD (which uses an SX28!). Mr. DeMeyer's requirements are greater than mine so the SX48 made sense relative to code space. My goal is to create a basic intervalometer — a microcontroller version of my original 555 device — and try to squeeze the works (control code, LCD

■ FIGURE 1. SIRCS 20-bit.







■ FIGURE 2. IR output.

interface, timing, etc.) into an SX28.

## CAMERA CONTROL

The one thing that my camera doesn't have is a manual control port — not a physical port, anyway. It does, however, have an IR port and a small remote that allows me to take pictures. Using January's project (SIRCS "sniffer"), I was able to determine the 12-bit SIRCS codes that the remote sends. The chore for this project, then, is to send the command that corresponds to the shutter button at the interval of my choosing. In addition to the SIRCS output, I'm going to add a couple open-collector outputs — just in case I want to control other devices later.

After determining the code and building it into a little test program, I got absolutely bupkis from the camera when transmitting the 12-bit SIRCS code. On the thought that the remote may be sending a sequence of codes, I connected the IR receiver output to a scope and boy was I surprised! The camera remote wasn't sending 12-bit codes at all. It was sending 20-bit codes!

I'd heard about 20-bit SIRCS codes but this is the first time I actually ran into them. In Figure 1, you can see the captured output of my camera remote when pressing the shutter button; it sends the same 20-bit code five consecutive times.

After a half day of Google-ing, I was never able to come up with a specification for the 20-bit SIRCS code but there was the suggestion that the 20-bit code used an eight-bit device code and a 12-bit command code. I updated the SIRCS sniffer code for 20 bits and used a Sony DVD remote to confirm this.

## TRANSMITTING SIRCS

Last time, we dealt with receiving the SIRCS stream which was pretty easy because it is simply a matter of accepting pulses from a standard IR detector. Transmitting isn't very complicated, but it's not just a matter of sending out a pulse stream; we also have to modulate the IR LED.

In order to keep everything in one chip, I decided to

connect both leads of the LED directly to the SX and use one of them (the cathode) as the modulation source; this needs to be 40 kHz. Keeping with the KISS philosophy, I set the interrupt to run at 80 kHz and then toggle the cathode through each pass to create the proper modulation signal.

The top of the ISR looks like this:

```
' =====
  INTERRUPT NOPRESERVE 80_000
' =====

Marker:
  isrFlag = 1

Modulate_LED:
  IrLedK = ~IrLedK
```

As with other programs, we set a bit called *isrFlag* at the top of the ISR; this is used by the foreground code for timing when needed. The modulation signal to the LED is simply a matter of inverting the output signal to the cathode. As this pin gets inverted 80,000 times a second, we end up with a modulation signal of 40 kHz with a duty cycle of 50 percent.

If you look at Figure 2, you'll see that both sides of the IR LED are tied to SX pins. The cathode pin provides the modulation and the anode gates the LED on and off. By making the anode pin high, the LED will be on whenever the cathode side is low. When the anode side is low, the LED will always be off, no matter what is happening on the cathode side.

Now that we can modulate the IR LED, we just have to create a control stream to the anode side to generate the SIRCS output. You'll remember that the SIRCS signal has a 2.4 millisecond start bit, "1" bits are 1.2 milliseconds wide, and "0" bits are 0.6 milliseconds wide — and every bit is spaced by a 0.6 millisecond off-time.

With the ISR running at 80 kHz, we can't use **PAUSE** or **PAUSEUS** so we'll need to create a set of custom routines. With the *isrFlag*, we're able to create sub-millisecond timing; this is done with the `DELAY_TIX` subroutine:

```

SUB DELAY_TIX
  isrTix  VAR  __WPARAM12

  \ SB __PARAMCNT.1
  \ CLR isrTix_

DO WHILE isrTix > 0
ASM
  CLRB isrFlag
  JNB isrFlag, $
  SUB isrTix_LSB, #1
  SUBB isrTix_MSB, /C
ENDASM
LOOP
ENDSUB

```

This routine takes the value passed to it and uses the *isrFlag* bit to decrement this value. You can see that within the loop the flag is first cleared and then the program waits for it to be set again which will happen during the next ISR. When the *isrFlag* is detected, the value in *isrTix* is decremented; once this value is zero, the routine exits.

At 80 kHz, the ISR is called every 12.5 microseconds; this is the timing value of each "tick." This means, then, that an SIRCS start bit will be 192 ticks, a 1 bit will be 96 ticks, and a 0 bit (and bit spacing) will be 48 ticks. The program defines constants called MS\_024, MS\_012, and MS\_006 for these values.

The TX\_SIRCS20 subroutine takes care of transmitting the 20-bit SIRCS code:

```

SUB TX_SIRCS20
  BANK @irWork

  irDevice = __PARAM1
  irCode = __WPARAM23

  irFrameTmr = MS_450

  ' start bit
  IrLeda = IR_ENABLE
  DELAY_TIX MS_024
  IrLeda = IR_DISABLE
  DELAY_TIX MS_006

  ' send command code
  FOR irBits = 1 TO 12
    IrLeda = IR_ENABLE
    IF irCode.0 = 1 THEN
      DELAY_TIX MS_012
    ELSE
      DELAY_TIX MS_006
    ENDIF
    IrLeda = IR_DISABLE
    DELAY_TIX MS_006
    irCode = irCode >> 1
  NEXT

  ' send device code
  FOR irBits = 1 TO 8
    IrLeda = IR_ENABLE
    IF irDevice.0 = 1 THEN
      DELAY_TIX MS_012
    ELSE
      DELAY_TIX MS_006
    ENDIF
  NEXT

```

```

  IrLeda = IR_DISABLE
  irDevice = irDevice >> 1
  DELAY_TIX MS_006
  NEXT

  ' complete frame space
  DO WHILE irFrameTmr > 0
  LOOP

  BANK
  ENDSUB

```

The routine has to accommodate 20 bits which means we'll be passing three bytes to it; to keep the call easy, I decided to structure it to accept a byte (the device code) and a word (the command code).

Before I get too far, let me point out something new: Inside this subroutine, the code is switching to a bank of variables called *irWork* using the @ directive. This is a very cool feature in SX/B 2.0 and saves a lot of code space when a subroutine can work within the confines of a single, 16-byte bank. Let's look at the declaration of *irWork*:

```

irWork  VAR  Byte (6) BANK
irFrameTmr  VAR  Word @irWork(0)
irCode  VAR  Word @irWork(2)
irDevice  VAR  Byte @irWork(4)
irBits  VAR  Byte @irWork(5)

```

Normally, we can only have bytes inside an array but when using the @ declaration as we've done here we can also declare words. Now, we do have to be a little careful with this style. Using these declarations, we're actually creating named offsets into the bank that is presently selected, so if we use one of these names while in another bank we will clobber something we don't want to. The advantage, however, is that we can use these elements just like ordinary variables once we switch to the bank; this keeps the amount of code SX/B generates smaller and by moving these variables to an array we preserve general RAM space. Let me just reiterate: We can treat these variables like normal program variables, but only when we're inside the bank — once we switch back to the general RAM bank, we should not use these variables.

I have no official documentation but information from what seems like a reliable source suggests that when a remote key is held down, the code is transmitted inside a 45 millisecond frame — and this was verified by my 'scope display. It stands to reason that we would want to create a 45 millisecond window in which to transmit the SIRCS code; for this we'll use *irFrameTmr*.

Management of this timer is handled inside the interrupt:

```

Update_Frame_Timer:
  ASM
  BANK irWork
  MOV W, irFrameTmr_LSB
  OR W, irFrameTmr_MSB
  JZ FT_Exit

```



```

SUB irFrameTmr_LSB, #1
SUBB irFrameTmr_MSB, /C

FT_Exit:
BANK __DEFAULT
ENDASM

```

The purpose of this code is to decrement *irFrameTmr* when it's greater than zero. Since *irFrameTmr* is a word (two bytes), the easiest way to check for zero (in Assembly) is to OR the upper and lower bytes together. If the result is zero, the **JZ** instruction will cause the code to jump to FT\_Exit. If *irFrameTmr* is not zero, then it gets decremented. We have to use two instructions to do this because it's a two byte value.

To enable this timer for the SIRCS window, we set it to 3600 as this is the number of 12.5 microsecond interrupt cycles in 45 milliseconds. This is done inside TX\_SIRCS20 using a constant called MS\_450.

Once the frame timer is started, we create the start pulse by activating the IR LED (anode high) and waiting 2.4 milliseconds; the DELAY\_TIX subroutine takes care of the timing in the foreground.

After the start pulse, we drop into a loop that will transmit the 12-bit command code — LSB-first. The IR LED is activated and then the proper delay is inserted: 1.2 milliseconds for a 1 bit or 0.6 milliseconds for a 0 bit. Per the spec, there is a 0.6 millisecond off-time between each bit. The IR code is shifted right after each bit to position the next. A second loop is used to transmit the eight-bit device code, again LSB-first. In all, 20 bits have been transmitted.

Finally, we wait for the 45 millisecond timer to expire before exiting. This allows the TX\_SIRCS20 routine to be called successively without violating the timing requirements of the protocol.

You're probably wondering: *What happens when the interrupt triggers in the middle of TX\_SIRCS20 — won't the bank setting be thrown off?* Good question, and the answer is no. At the start of the interrupt, the SX automatically saves a few key registers — one of them is the FSR (bank pointer) — and this is restored when the interrupt terminates.

## LCD CONTROL

Suffice it to say that I and

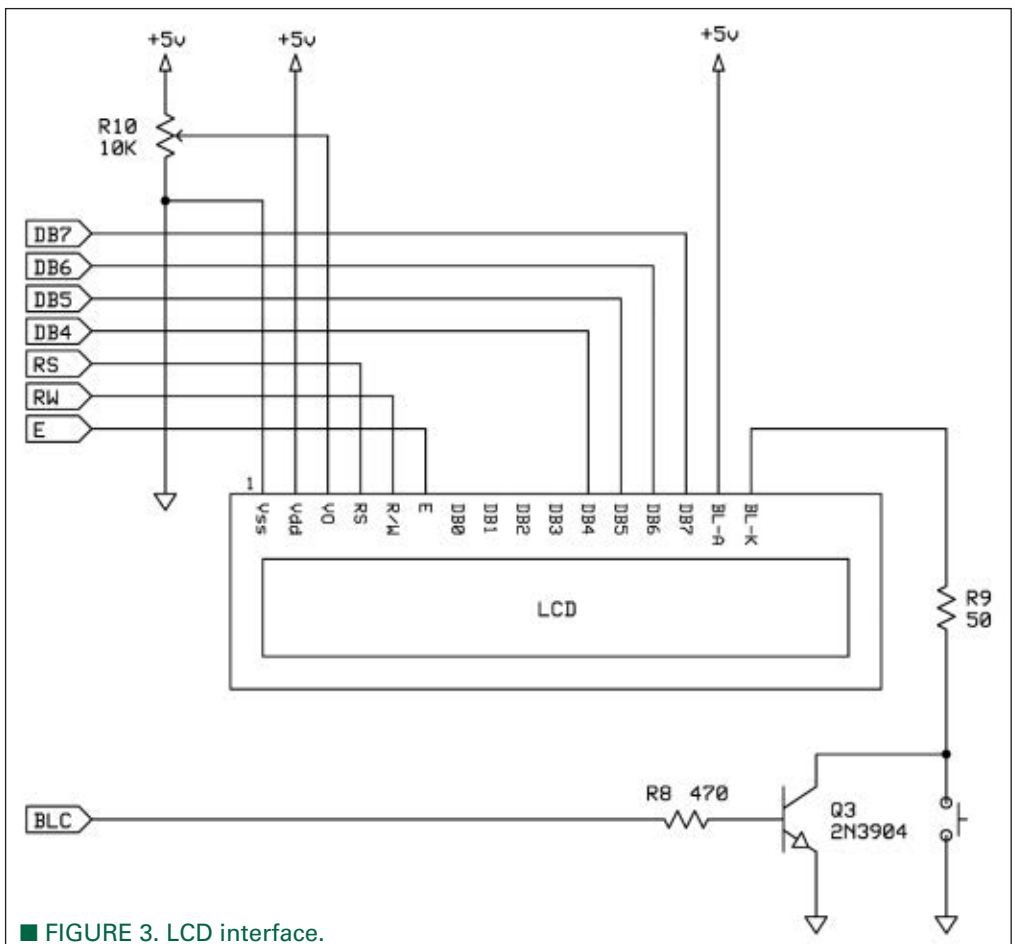
others have written a boatload of material on LCD interfacing in the pages of *Nuts & Volts* so I'm not going to go into detail here except to say that I'm using a four-bit interface to minimize I/O requirements (see Figure 3). This means, though, that writing to the LCD requires two nibble writes. This is handled by LCD\_OUT which also preserves the backlight control pin and the RS line (command or character mode) of the LCD.

One of the choices I made was to forego reading the LCD busy flag. This means that there is standardized timing built into the write cycle and that I have to remember to include a two millisecond or greater delay after using the clear (\$01) and home (\$02) commands. The initialization code disables window scrolling so the home command should never be needed; remembering a short delay after clearing the LCD won't be a problem.

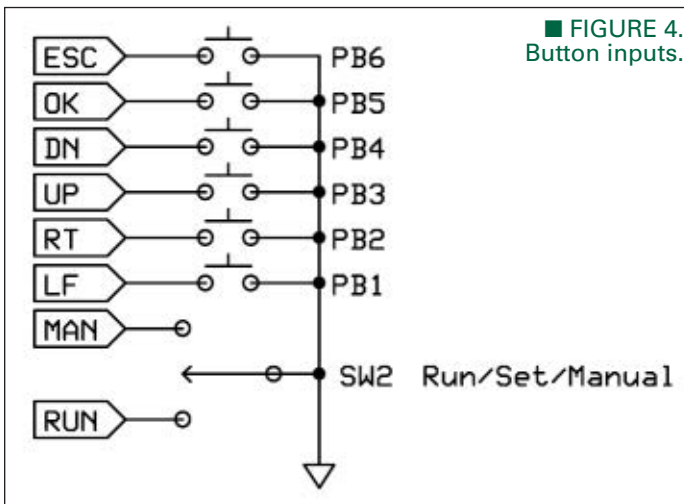
While I don't anticipate needing the backlight for this project, I've added control from the port and a manual switch — just in case I'm doing some late-night photography.

## ACCEPTING USER INPUT

My intervalometer has three modes: setup, run, and manual. These modes can be handled with a three-position toggle switch and two I/O bits. For entering information, I'm using the other six bits on the same port



■ FIGURE 3. LCD interface.



to create a generic interface: Up, Down, Left, Right, OK, and Escape. Using the SX's internal pull-ups adding the interface is simple (see Figure 4).

We all know that we should debounce digital inputs; we also know that this takes time. After some thought, I decided to put the debouncing code inside the interrupt. By doing this, a set of flags can be used to indicate that an input is valid. Here's the code for that:

```
Debounce:
    ASM
    BANK btnWork
    INC tmrlms
    CJNE tmrlms, #80, DB_Exit
    CLR tmrlms
    INC tmrScan

DB_Check:
    CJB tmrScan, #50, DB_Port_Scan
    CLR tmrScan
    MOV btnFlags, btnTemp
    MOV btnTemp, #%1111_1111
    JMP DB_Exit

DB_Port_Scan:
    MOV W, /UserIn
    AND W, btnTemp
    MOV btnTemp, W

DB_Exit:
    BANK __DEFAULT
    ENDASM
```

This code uses two timers: one that counts the number of ISR cycles in one millisecond (80), and a second that sets the debounce timing. In this case, I'm using 50 milliseconds.

At the beginning of each 50 millisecond debounce period, a temporary variable (*btnTemp*) is set to %1111\_1111. We start the debounce scan assuming a button is pressed (1 is pressed, 0 is not pressed). On each millisecond tick through the cycle, the temporary variable is ANDed with the button port — any pin that is active will remain 1 in the temporary variable.

Note that as we're using active-low inputs, we have to

invert the port value during the scan.

At the end of the debounce period, the temporary variable is moved to a global variable called *btnFlags* for use by the foreground program. This cycle runs constantly so the *btnFlags* variable is updated every 50 milliseconds. In the foreground, we don't have to do anything except check the bits in *btnFlags* to see if any inputs are active.

## OPERATION

I use a toggle switch for the mode selector as my time spent developing sprinkler timers for Toro taught me that users generally don't like navigating menus for operational modes — just settings. When this switch is in the middle position, we're in setup mode that allows us to adjust the interval timing for run mode. The program will allow any interval — with one-second resolution — from one second to 24 hours. Time will be displayed on the LCD as 00:00:00 to 24:00:00.

In setup mode, the LCD will appear as in Figure 5 (top). An underline cursor will denote the field that can be updated: seconds, minutes, or hours. These values are stored in an array and use a BCD format like common RTCs (DS1302, etc.).

Having a single menu item with three fields meant that the code to update the interval was actually quite manageable, and using the Up, Down, Left, Right, OK, and Escape buttons makes it intuitive:

```
Setup_Interval:
    LCD_CMD LcdCrscrOff
    LCD_CMD LcdCls
    DELAY_MS 3
    LCD_STR "SETUP"

Setup_Reload:
    iChanged = No
    PUT cntDn, iTime(0) TO iTime(2)

Setup_Show_Time:
    LCD_CMD LcdCrscrOff
    cmdChar = LcdLine1 + 7
    LCD_CMD cmdChar

    IF iChanged THEN
        LCD_OUT " "
    ELSE
        LCD_OUT " "
    ENDIF

    LCD_HEX2 cdHrs
    LCD_OUT ":"
    LCD_HEX2 cdMins
    LCD_OUT ":"
    LCD_HEX2 cdSecs
```

At the start, we clear the screen and display the current interval setting. The interval has been moved into a temporary array called *cntDn*; we'll manipulate this array instead of the present user setting.

By using a temporary array for the interval, we actually have a method to "undo" any changes. You'll notice that right before the time elements are written to the LCD, a



bit flag called *iChanged* is examined and if this bit is 1 we print an asterisk; otherwise, a space. The *iChanged* flag lets us know that the temporary array has been changed and may not match the internal setting.

The next section of code positions and displays the underline cursor, then scans the inputs by looking at *btnFlags*:

```
Setup_Field:
  LCD_CMD LcdCrSrOff
  LOOKUP iState, 15, 12, 9, cmdChar
  cmdChar = cmdChar + LcdLine1
  LCD_CMD cmdChar
  LCD_CMD LcdCrSrOn
  DELAY_MS 200

Setup_Wait_Button:
  pgmMode = btnFlags & %0000_0011
  IF pgmMode <> %00 THEN Main

  tmpB1 = btnFlags & %1111_1100
  tmpB1 = BIT_COUNT tmpB1
  IF tmpB1 <> 1 THEN Setup_Wait_Button

  LOOKUP iState, $59, $59, $24, fldMax

  IF btnMnuUp THEN Setup_Inc_Field
  IF btnMnuDn THEN Setup_Dec_Field
  IF btnMnuLf THEN Setup_Next_Field
  IF btnMnuRt THEN Setup_Prev_Field
  IF btnMnuOK THEN Setup_Set_Interval
  IF btnMnuEsc THEN Setup_Reload
```

The input field state (seconds, minutes, hours) is tracked in a variable called *iState* and this is used with a **LOOKUP** table to get the cursor position in the time display; as the program increments/decrements in ones, the cursor is displayed under the 1's digit in each field. I added a short delay after the cursor updating so that I can hold a button down and still see changes in the display.

At *Setup\_Wait\_Button*, we look at our debounced inputs stored in *btnFlags*. The first thing to do is make sure we're still in setup mode. If we are, then we can mask out the mode buttons and check to see if any button is pressed. To prevent ambiguities, we check the number of active inputs. If only one button is pressed, we can drop through to the handlers.

Another **LOOKUP** table is used to set the maximum value for the current field; minutes and seconds have a logical range of \$00 to \$59 (BCD), and we're going to allow the hour's field to go all the way to \$24.

The last step in this section is to jump to the appropriate handler code for each button. Let's start with changing the field values (Up and Down buttons):

```
Setup_Inc_Field:
  iChanged = Yes
  cntDn(iState) = ADD_BCD cntDn(iState), 1
  IF cntDn(iState) > fldMax THEN
    cntDn(iState) = $00
  ENDIF
  IF cdHrs = $24 THEN
    PUT cdSecs, $00, $00
```

```
ENDIF
GOTO Setup_Show_Time

Setup_Dec_Field:
  iChanged = Yes
  cntDn(iState) = SUB_BCD cntDn(iState), 1
  IF cntDn(iState) > fldMax THEN
    cntDn(iState) = fldMax
  ENDIF
  IF cdHrs = $24 THEN
    PUT cdSecs, $00, $00
  ENDIF
  GOTO Setup_Show_Time
```

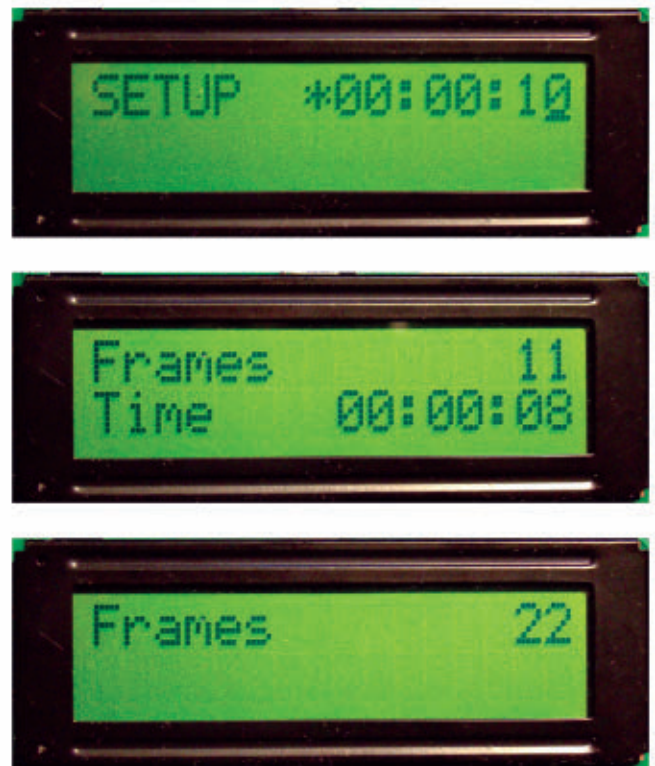
As you can see, these routines are nearly identical. The first will increment the current field and if it is bumped beyond its maximum value, it is reset to zero. There is a limit check on the hours field and when the hours is set to \$24, the seconds and minutes fields are cleared to \$00 – this limits the maximum interval time to 24:00:00.

The decrement routine is a virtual copy except that it handles under-flow by setting the field value to its maximum. As the fields are expressed in BCD, we use the **ADD\_BCD** and **DEC\_BCD** functions; these are SX/B shells around some neat code I found on [www.sxlist.com](http://www.sxlist.com) (which is a great resource for SX programmers).

Moving the cursor is trivial – just a matter of incrementing *iState* and dealing with roll-over or roll-under:

```
Setup_Next_Field:
  INC iState
  IF iState > 2 THEN
```

■ FIGURE 5. Intervalometer displays.



```

iState = 0
ENDIF
GOTO Setup_Mode

Setup_Prev_Field:
DEC iState
IF iState > 2 THEN
iState = 2
ENDIF
GOTO Setup_Mode

```

After adjusting the input state, the program is routed back to `Setup_Mode` where the cursor is re-displayed.

Finally, when we press the OK button, we want to transfer the contents to the operation interval array:

```

Setup_Set_Interval:
PUT iTime, cntDn(0) TO cntDn(2)
iChanged = No
GOTO Setup_Show_Time

```

SX/B 2.0 has an improved version of **PUT** which makes moving elements from one array to another very simple. As you can see, we're moving the contents of the temporary buffer (`cntDn`) into `iTime`. The next step is to clear the `iChanged` flag which will remove the asterisk from the display to let us know that the new interval is set.

There is no special handler for the Escape button; if we press it, the program jumps back to `Setup_Reload` which will move the current interval (`iTime`) into the temporary buffer (`cntDn`). This process also clears the `iChanged` flag as the temporary and user intervals now match.

## LET THE PHOTOS FLY

When I first started this project, I created a background RTC and was going to compare it to the user interval but after working with the code, I concluded it would be easier just to move the interval into a temporary buffer and count down in one second units. To keep precise, however, means that the one second timing would have to be solid and not deviate – sounds like another routine in the interrupt.

The code is really easy. We count up to 80,000 (the interrupt rate) and when we get there, we set a flag and restart the counter from zero. The foreground is responsible for dealing with and resetting the flag:

```

OneSec_Timer:
ASM
BANK oneSec
INC osB0
ADDB osB1, Z
ADDB osB2, Z
CJNE osB0, #$80, OS_Exit
CJNE osB1, #$38, OS_Exit
CJNE osB2, #$01, OS_Exit

OS_Reset:
CLR osB0

```

```

CLR osB1
CLR osB2
SETB osFlag

OS_Exit:
BANK __DEFAULT
ENDASM

```

It takes three bytes to count up to 80,000 so I call them `osB0` (lowest byte), `osB1` (middle byte), and `osB2` (highest byte). When all three bytes hit their target values, the code drops through to `OS_Reset` which restarts the timer and sets `osFlag` which is a bit in the global `flags` variable.

Okay, let's put it to use. When we switch to run mode, the LCD will show the current frame count and the current time left in the interval, as in Figure 5 (middle). I decided to snap a frame at the beginning of the cycle, mostly to let me know that I have communication with the camera (we can use manual mode to trouble-shoot if a problem arises).

As I told you earlier, my camera uses an IR input so the `SHOOT_FRAME` subroutine uses `TX_SRICS20`, as well as enabling a secondary output bit:

```

SUB SHOOT_FRAME
Opt1 = IsOn
FOR tmpB1 = 1 TO 5
TX_SRICS20 %1111_0001, %1101_0010_1101
NEXT
Opt1 = IsOff
ENDSUB

```

Pretty easy, right? We turn on the `Opt1` bit which I'm using with an LED as a visual indicator. This output also connects to a transistor circuit which can be used to drive an external relay. In order to match the output of my camera's remote, I send the 20-bit shutter code five times using a **FOR-NEXT** loop. After this, the secondary output is turned off and we're done – the whole process takes about 220 milliseconds. Again, we don't have to worry about this upsetting our interval timing as that is being updated in the interrupt.

We're nearly there. Let's look at the code that monitors the one second flag and deals with the interval:

```

Int_Wait_1Sec:
pgmMode = btnFlags & %0000_0011
IF pgmMode <> %01 THEN Main

IF osFlag = IsOff THEN Int_Wait_1Sec
osFlag = IsOff

Int_Update_Time:
cdSecs = SUB_BCD cdSecs, 1
IF cdSecs > $59 THEN
cdSecs = $59
cdMins = SUB_BCD cdMins, 1
IF cdMins > $59 THEN
cdMins = $59
IF cdHrs > $00 THEN
cdHrs = SUB_BCD cdHrs, 1

```



```

ENDIF
ENDIF
ENDIF

Int_Check_Zero:
IF cdSecs > $00 THEN Int_Show_Time
IF cdMins > $00 THEN Int_Show_Time
IF cdHrs > $00 THEN Int_Show_Time

LCD_CMD LcdCrSrL
LCD_OUT "0"
shootNow = Yes
GOTO Int_Reload

```

At the top, we double-check the mode switch and the one second flag. We'll loop right here until the mode changes or the one-second flag goes high. When the flag is detected, we immediately clear it and drop down to Int\_Update\_Time to decrement the interval.

As in the setup mode, we use the SUB\_BCD function to decrement the seconds register and when that underflows we cascade to minutes and hours. As long as there is any time left, the program is routed back to Int\_Show\_Time which updates the display. Otherwise, we drop through.

Since the camera output takes about 220 milliseconds, I decided to clean up the display by moving the cursor left and printing a 0; this shows 00:00:00 during the time the camera control output is active. A flag called *shootNow* is used to enable the camera output at the top of the interval loop. This also updates the variable called *frames* and sends it to line one of the LCD:

```

SUB SHOW_FRAMES
sfChar  VAR  tmpB3
sfIdx   VAR  tmpB4

sfChar = LcdLine1 + 11
LCD_CMD sfChar
STR nStr, frames
FOR sfIdx = 0 TO 4
LCD_OUT nStr(sfIdx)
NEXT
ENDSUB

```

There is a new function in SX/B 2.0 called **STR** that will convert a number to a string. As this generates a fair bit of code, I've wrapped it into the previous subroutine so that it can be called from run and manual modes without using extra code space. The default output is to pad the number with spaces, and it has optional modes that will pad with zeros or extract to decimal digits — a very handy addition to SX/B.

Okay, I know this was a bit of a bear and we couldn't cover everything but I hope you have as much fun with the code as I have — all 900 lines of it! Even if you don't build the intervalometer,

you should still be able to find a lot of useable code snippets here that will help in other projects. I always do my best to make code as portable and re-usable as possible as this makes future projects easier to put together.

## TIME-LAPSE MATH

Now that you know how the intervalometer works, let me show you how to work the intervalometer. Let's say we wanted to recreate the Los Angeles to Las Vegas time-lapse movie using a new digital camera. What interval setting would we need to use? To find this setting, we need to know three things:

- 1) Projected frame rate
- 2) On-screen time
- 3) Event duration

The projected frame rate is usually going to be 30 (NTSC) or 25 (PAL, etc.), though you could do a custom frame if your intention is video for the Internet. Let's use 30 for the time-being.

With the projected frame rate and the on-screen time, we can calculate the total number of frames to shoot: 1,800.

$$3 \text{ mins} \times 60 \text{ secs/min} \times 30 \text{ frames/sec} = 5,400 \text{ frames}$$

The next step is to calculate the event time in seconds:

## BILL OF MATERIALS

ITEM	DESCRIPTION	SUPPLIER/PART #
► C1-C2 *	47 µF	Mouser/647-UVR1V470MDD
► C3	0.1 µF	Mouser/80-C315C104M5U
► D1, D3	LED	Mouser/859-LTL-4222N
► D2	LED (IR)	Mouser/604-WP7113F3BT
► J1 *	2.1 mm	Mouser/806-KLDX-0202-A
► JP1-JP2	0.1 male header	Mouser/517-6111TG
► LCD	2x16	Mouser/763-NHD-0216PZ-FLYBW
► OSC	20 MHz	Parallax/250-02060
► PB1-PB7	Pushbutton	Mouser/104-0013-EVX
► PGM *	0.1 R/A header	Mouser/517-5111TG
► Q1-Q3	2N3904	Mouser/610-2N3904
► R1	1K	Mouser/299-1K-RC
► R2-R3	10K	Mouser/299-10K-RC
► R4	100Ω	Mouser/299-100-RC
► R5-R8	470Ω	Mouser/299-470-RC
► R9	47Ω	Mouser/299-47-RC
► R10	10K pot	Mouser/652-3352T-1-103LF
► SW2	SPDT toggle	Mouser/506-A103SYZQ04
► U1 *	SX28AC/DP	Parallax/SX28AC/DP-G
► VR1 *	TS2940CZ50	Mouser/821-TS2940CZ50
► X1-X2	3-pos terminal block	Mouser/571-2828363

Optional (Replaces \*)  
SX28 Proto Board, Parallax 45302 Power Supply



-



A photograph of Kristin O'Friel and Che-Wei Wang standing in the main hall of Grand Central Terminal. Kristin is on the left, wearing a dark coat and a yellow scarf, with her hand on her hip. Che-Wei is on the right, wearing a grey sweater and jeans, holding a red knitted hat. The background shows the iconic architecture of the terminal, including large arched windows and a clock face. A small, round, metallic object lies on the floor near Che-Wei's feet.

## Let your geek shine.

Meet Kristin O'Friel and Che-Wei Wang, inventors of Momo. Momo is a haptic GPS navigational device born out of a physical computing class project at ITP. Kristin and Che-Wei used SparkFun products to develop their Momo prototype.

The tools are out there - from GPS modules to microcontrollers, tutorials to forums. Find the resources you need and let your geek shine too.



**Sharing Ingenuity**

[WWW.SPARKFUN.COM](http://WWW.SPARKFUN.COM)

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For more information on Momo visit [www.momobots.com](http://www.momobots.com). For more information on ITP and the Tisch School of the Arts at NYU visit [itp.nyu.edu/itp](http://itp.nyu.edu/itp).



# IT'S SPRINGTIME AT RAMSEY!

## Digital Controlled FM Stereo Transmitters

- ✓ PLL synthesized for drift free operation
- ✓ Front panel digital control and display of all settings and parameters!
- ✓ Professional metal case for noise-free operation
- ✓ EMI filtering on audio and power inputs
- ✓ Super audio quality, rivals commercial broadcasts
- ✓ Available in domestic kit or factory assembled export versions

For nearly a decade we've been the leader in hobbyist FM radio transmitters. We told our engineers we wanted a new technology transmitter that would provide FM100 series quality without the advanced mixer features. They took it as a challenge and designed not one, but TWO transmitters!



The FM30 is designed using through-hole technology and components and is available only as a do-it-yourself kit with a 25mW output very similar to our FM25 series. Then the engineers redesigned their brand-new design using surface mount technology (SMT) for a very special factory assembled and tested FM35WT version with 1W output for our export only market!

All settings can be changed without taking the cover off! Enter the setup mode from the front panel and step through the menu to make all of your adjustments. A two line LCD display shows you all the settings! In addition to the LCD display, a front panel LED indicates PLL lock so you know you are transmitting. Besides frequency selection, front panel control and display gives you 256 steps of audio volume (left and right combined) as well as RF output power. A separate balance setting compensates for left/right differences in audio level. In addition to settings, the LCD display shows you "Quality of Signal" to help you set your levels for optimum sound quality. And of course, all settings are stored in non-volatile memory for future use!

Both the FM30 and FM35WT operate on 13.8 to 16VDC and include a 15VDC plug-in power supply. The stylish black metal case measures 5.55"W x 6.45"D x 1.5"H. (Note: After assembly of this do-it-yourself hobby kit, the user is responsible for complying with all FCC rules & regulations within the US, or any regulations of their respective governing body. FM35BWT is for export use and can only be shipped to locations outside the continental US or valid APO/FPO addresses or valid customs brokers for end delivery outside the continental US.)

**FM30B** Digital FM Stereo Transmitter Kit, 0-25mW, Black **\$199.95**  
**FM35BWT** Digital FM Stereo Transmitter, Assembled, 1W, Black (Export ONLY) **\$299.95**

## Pocket Audio Generator

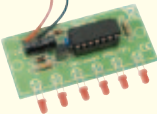
A perfect test source for stereo line inputs on any amplifier or mixer. Provides 50Hz, 100Hz, 1kHz, 10kHz, & 20kHz tones, plus 32 bit digital pink noise. Great to help you identify cables or left/right reversals! Stereo RCA line level outputs. Uses 2xCR2025, not included.



**K8065** Pocket Audio Generator Kit **\$32.95**

## Mini LED Light Chaser

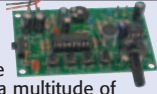
This little kit flashes six high intensity LEDs sequentially in order. Just like the K80302 to the right does with incandescent lights. Makes a great mini attention getter for signs, model trains, and even RC cars. Runs on a standard 9V battery.



**MK173** Mini LED Light Chaser Kit **\$13.95**

## Digital Voice Changer

This voice changer kit is a riot! Just like the expensive units you hear the DJ's use, it changes your voice with a multitude of effects! You can sound just like a robot, you can even ad vibrato to your voice! 1.5W speaker output plus a line level output! Runs on a standard 9V battery.



**MK171** Voice Changer Kit **\$14.95**

## Laser Trip Senser Alarm

True laser protects over 500 yards! At last within the reach of the hobbyist, this neat kit uses a standard laser pointer (included) to provide both audible and visual alert of a broken path. 5A relay makes it simple to interface! Breakaway board to separate sections.

**LTS1** Laser Trip Sensor Alarm Kit **\$29.95**

## Electret Condenser Mic

This extremely sensitive 3/8" mic has a built-in FET preamplifier! It's a great replacement mic, or a perfect answer to add a mic to your project. Powered by 3-15VDC, and we even include coupling cap and a current limiting resistor! Extremely popular!



**MC1** Mini Electret Condenser Mic Kit **\$3.95**

## Pocket Vu Meter

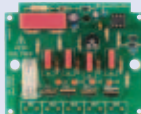
Hand held audio level meter that fits in your pocket! Built-in mic picks up music and audio and displays it on an LED bargraph. Includes enclosure shown. Runs on one 3V Li-Ion button cell, not included. If you ever wanted an easy way to measure audio levels, this is it!



**MK146** Pocket Vu Meter Kit **\$8.95**

## Running Light Controller

Controls and powers 4 incandescent lights so they appear to "travel" back and forth (Like the hood on KITT!). Great for the dance floor or promotional material attention getters, exhibits, or shows. Runs on 112-240VAC.



**K8032** 4-Channel Running Light Kit **\$38.95**

## Steam Engine & Whistle

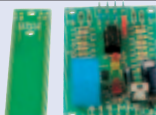
Simulates the sound of a vintage steam engine locomotive and whistle! Also provides variable "engine speed" as well as volume, and at the touch of a button the steam whistle blows! Includes speaker. Runs on a standard 9V battery.



**MK134** Steam Engine & Whistle Kit **\$11.95**

## Liquid Level Controller

Not just an alarm, but gives you a LED display of low, middle, or high levels! You can also set it to sound an alarm at the high or low condition. Provides a 2A 240VAC rated relay output. Runs on 12-14VAC or 16-18VDC.



**K2639** Liquid Level Controller Kit **\$23.95**

## Sniff-It RF Detector Probe

Measure RF with your standard DMM or VOM! This extremely sensitive RF detector probe connects to any voltmeter and allows you to measure RF from 100kHz to over 1GHz! So sensitive it can be used as a RF field strength meter!



**RF1** Sniff-It RF Detector Probe Kit **\$27.95**

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## Hi-Res Elevation Sensor

- ✓ Elevation resolution to 1/3"!
- ✓ Pressure resolution to .0001 kPa!
- ✓ 128x64 pixel graphical display!
- ✓ USB computer interface!
- ✓ Built-in Li-Ion battery!



The response to the UP24 was incredible! Customers from professional land surveyors, meteorologists, scientists, pilots and hikers to the curious hobbyist were overwhelmed with its sensitivity and accuracy. Reading realtime elevation to a third of an inch blew their minds! We made it even better...introducing the next generation UP24B!

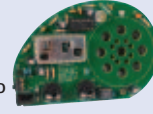
First, for extended field use, we designed an internal lithium ion power cell and a state of the art power management system. Now you can charge it while it's connected to your USB connection, or use an external charger! Next we added a "MARK" feature. This allows storing a single data point reading when YOU want instead of blindly storing readings at the selected sample rate from an external switch (dry or electronic). Data is in comma delimited form for easy spreadsheet use.

Then we streamlined the controls to make a more compact profile. The rotary menu navigation dial has been replaced by contactless proximity buttons for more reliable operation! Just touch your way through the menus without any dials or switches! All in a handheld device that weighs less than 4oz! Visit [www.ramseykits.com](http://www.ramseykits.com) for details, there's just too much to fit here!

**UP24B** Elevation/Pressure Sens Kit **\$239.95**  
**UP24BWT** UP24B Factory Asmb **\$299.95**

## Portable FM Radio

Now you can build yourself a little FM radio receiver, learn about FM receivers, and have a neat little radio in the end! The RF front end is pre-assembled to make it simple. Receives the whole FM broadcast band 88-108 MHz. Runs on 12VDC.



**MK118** FM Radio Receiver Kit **\$21.95**

## High Power LED Driver

High power LED's have finally found their way into the hobbyist budget, but now you need a driver! This little board provides the accurate and constant current need to drive them. Delivers 350mA or 700mA at a constant current



**K8071** High Power LED Driver Kit **\$14.95**

## Electronic Watch Dog

A barking dog on a PC board! And you don't have to feed it! Generates 2 different selectable barking dog sounds. Plus a built-in mic senses noise and can be set to bark when it hears it! Even includes adjustable sensitivity! Eats 2-8VAC or 9-12VDC, it's not fussy!



**K2655** Electronic Watch Dog Kit **\$39.95**

## Call Code Activated Switch

What a concept... control things by the number of rings on your phone, and the number of rings is adjustable! Plus you can store up to 42 different codes! Activation can switch on a timer from 3 seconds to 56 hours. Relay output. Runs on 12VDC.



**K2650** Call Code Activated Switch Kit **\$29.95**

## Broadband RF Preamp

Need to "perk-up" your counter or other equipment to read weak signals? This preamp has low noise and yet provides 25dB gain from 1MHz to well over 1GHz. Output can reach 100mW! Runs on 12 volts AC or DC or the included 110VAC PS. Assmb.



**PR2** Broadband RF Preamp **\$69.95**



### Davis OBDII CarChip Pro

The incredible OBDII plug-in monitor that has everyone talking! Once plugged into your vehicle it monitors up to 300 hours of trip data, from speed braking, acceleration, RPM and a whole lot more. Reads and resets your check engine light, and more!



8226 CarChip Pro OBDII Monitor \$99.95

### LED Blinky

Our #1 Mini-Kit for over 35 years! Alternately flashes two jumbo red LED's. Great for signs, name badges, model railroading, and more. Used throughout the world as the first learning kit for students young and old! Great solder practice kit. Runs on 3-15 VDC.



BL1 LED Blinky Kit \$7.95

### Universal Timer

Build a time delay, keep something on for a preset time, provide clock pulses or provide an audio tone, all using the versatile 555 timer chip! Comes with circuit theory and a lots of application ideas and schematics to help you learn the 555 timer. 5-15VDC.



UT5 Universal Timer Kit \$9.95

### RF Preamplifier

The famous RF preamp that's been written up in the radio & electronics magazines! This super broadband preamp covers 100 KHz to 1000 MHz! Unconditionally stable gain is greater than 16dB while noise is less than 4dB! 50-75 ohm input. Runs on 12-15 VDC.



SA7 RF Preamp Kit \$19.95

### Mad Blaster Warble Alarm

If you need to simply get attention, the "Mad Blaster" is the answer, producing a LOUD ear shattering raucous racket! Super for car and home alarms as well. Drives any speaker. Runs on 9-12VDC.



MB1 Mad Blaster Warble Alarm Kit \$9.95

### Water Sensor Alarm

This little \$7 kit can really "bail you out"! Simply mount the alarm where you want to detect water level problems (sump pump!). When the water touches the contacts the alarm goes off! Sensor can even be remotely located. Runs on a standard 9V battery.



MK108 Water Sensor Alarm Kit \$6.95

### Air Blasting Ion Generator

Generates negative ions along with a hefty blast of fresh air, all without any noise! The steady state DC voltage generates 7.5kV DC negative at 400uA, and that's LOTS of ions! Includes 7 wind tubes for max air! Runs on 12-15VDC.



IG7 Ion Generator Kit \$64.95

### IC AM/FM Radio Lab

Learn all about AM/FM radio theory, IC theory, and end up with a high quality radio! Extensive step-by-step instructions guide you through theory, parts descriptions, and the hows and whys of IC design. Runs on a standard 9V battery.



AMFM108K AM/FM IC Radio Lab Kit \$34.95

## Just Off The Press!

Get the new 2009 Ramsey Hobby Catalog! 96 value packed pages of the neatest goodies around with lots of new stuff! Order yours today on line or give us a call... Or download the PDF at [www.ramseykits.com/catalog](http://www.ramseykits.com/catalog)!



### Practice Guitar Amp & DI

Practice your guitar without driving your family or neighbors nuts! Works with any electric, acoustic-electric, or bass guitar. Plug your MP3 player into the aux input and practice to your favorite music! Drives standard headphones and also works as a great DI!



PGA1 Personal Practice Guitar Amp Kit \$64.95

### Laser Light Show

Just like the big concerts, you can impress your friends with your own laser light show! Audio input modulates the laser display to your favorite music! Adjustable pattern & speed. Runs on 6-12VDC.



LLS1 Laser Light Show Kit \$49.95

### Voice Activated Switch

Voice activated (VOX) provides a switched output when it hears a sound. Great for a hands free PTT switch or to turn on a recorder or light! Directly switches relays or low voltage loads up to 100mA. Runs on 6-12 VDC.



VS1 Voice Switch Kit \$9.95

### Touch Switch

Touch on, touch off, or momentary touch hold, it's your choice with this little kit! Uses CMOS technology. Actually includes TWO totally separate touch circuits on the board! Drives any low voltage load up to 100mA. Runs on 6-12 VDC.



TS1 Touch Switch Kit \$9.95

### DTMF Encoder Decoder

Decodes standard Touch Tones from telephones, radio, or any audio source. Detects and decodes any single digit and provides a closure to ground up to 20mA. Great for remote tone control. Runs on 5VDC.



TT7 DTMF Encode/Decode Kit \$24.95

### RF Actuated Relay

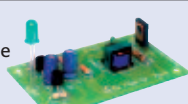
Just what you need when adding a preamp or power amp in line with an antenna! Auto senses RF and closes an on-board DPDT relay that's good to UHF at 100W! Also great to protect expensive RF test equipment. Senses as low as 50mW!



RFS1 RF Actuated Relay Kit \$19.95

### Tickle-Stick Shocker

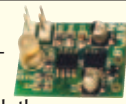
The kit has a pulsing 80 volt tickle output and a mischievous blinking LED. And who can resist a blinking light and an unlabeled switch! Great fun for your desk, "Hey, I told you not to touch!" Runs on 3-6 VDC.



TS4 Tickle Stick Kit \$12.95

### SMT Multi-Color Blinky

The ultimate blinky kit! The 8-pin micro-controller drives a very special RGB LED in 16 million color combinations! Uses PWM methods to generate any color with the micro, with switchable speed selection. SMT construction with extra parts when you lose them! 9V battery.



SBRGB1 SMT Multi-Color Blinky Kit \$29.95

### Passive Aircraft Monitor

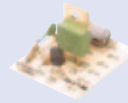
The hit of the decade! Our patented receiver hears the entire aircraft band without any tuning! Passive design has no LO, therefore can be used on board aircraft! Perfect for air-shows, hears the active traffic as it happens! Available kit or factory assembled.



ABM1 Passive Aircraft Rcvr Kit \$89.95

### Electronic Siren

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SM3 Electronic Siren Kit \$7.95

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# Q&A

## WHAT'S UP:

Join us as we delve into the basics of electronics as applied to every day problems, like:



Measuring Energy Use



More On Oscillators



Flat Panel TVs

### ■ WITH RUSSELL KINCAID

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist. Feel free to participate with your questions, comments, or suggestions.

Send all questions and comments to:

**Q&A@nutsvolts.com**

## ASCII TO BAUDOT CODE CONVERTER

**Q** Taking a giant leap backwards, I'm looking for an ASCII to Baudot converter circuit that works at 45 baud. Thank you!

— **Craig Edmonds**

**A** I assume the Baudot code you refer to is the Western Union teletype code in common use. Converting the seven bit ASCII word to the five bit Baudot word is just a program for a microcomputer; but probably more than I can do at my level of learning.

Fortunately, the problem has been solved already. I found a UK paper that described such a system but it would have been too big a job for me. Don't despair, there is a kit available from Gil Smith; check out [www.baudot.net/tty-connect.htm](http://www.baudot.net/tty-connect.htm). Gil told me that this is a hobby with him. The board is not in production, but you can buy one for \$30 and you supply your own components.

## SCHOOLS

**Q** I read *Nuts & Volts* all the time even though it's way out of my league; this is why I'm writing to you. Is

there any possibility that you might know of a school that teaches electronics? I'm a working adult, so I don't have time to go to a regular college. Perhaps you might know of a private school or courses in the New York City area. This is something I've been interested in for a long time so any help would be greatly appreciated.

— **Anthony Polizzi**

**A** The best school in your area is New York City College of Technology (City Tech); it offers an Associates degree in Electrical Engineering Technology, but it is a day school. I think what you want is an online school like Cleveland Institute of Electronics or Penn Foster Career School. These both offer basic electricity and work up from there. Many schools (such as ITT Tech) offer Information Technology courses but I don't think that is what you are looking for. Request information from these schools, and decide which courses will lead in the direction you want to go.

## MEASURING ENERGY USE

**Q** I'd like to calculate the energy in mAh consumed over a long period by a system consisting of a

microprocessor and an LED. The LED flashes according to a programmed sequence consisting of pulses at a constant frequency and varying pulse width in a repeating pattern. The pattern is complex and lengthy, but averages out reasonably well over about an hour. I can measure the time it takes for batteries to expire, but batteries last for months and a test series would last for years. Is there any other way besides battery tests to predict battery life in this application? I have an oscilloscope, an ammeter, and a precision power supply.

— **James Turner**

**A** Measuring an average over a long period of time would require a microprocessor, but since you already have one, I suggest that you modify the program to add all the on times over a period of an hour, then turn on the LED for the total time. You know the current drawn during the on time and the operating current of the micro.

An alternative is to locate an electroplating unit that is designed to measure elapsed time. The plating builds up while the LED is on, so you can measure the thickness after an hour or 10 hours to determine the total on time. I had one of those 40 years ago but don't remember the name or if it is still available.

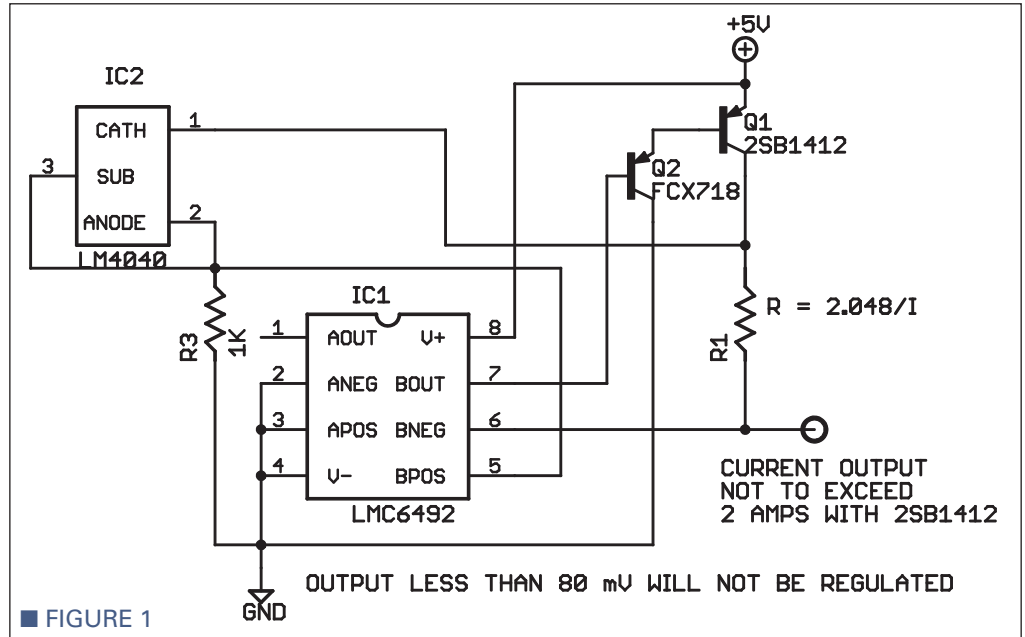


## OSCILLATORS

**Q** Could you explain the Barkhausen criteria and conditions for oscillation? I understand the loop gain must be 1.0 but what about the phase conditions? How are these conditions met differently by a Colpitts oscillator and a Wein Bridge oscillator?

**A** The Barkhausen criteria are that the gain around the positive feedback loop must be at least one and the phase must be zero degrees. According to Wikipedia, these are necessary but insufficient criteria for oscillation. Nyquist further adds that for stability, the real part of all poles must be negative. This implies that there are circuits which have closed loop gain of +1 and zero phase that do not oscillate. I have never run across such a circuit. In my experience, circuits follow Murphy's Law: If it is possible for anything to go wrong, it will.

The Wein Bridge (Figure 1) is popular in oscillators because there is leading phase due to C1 and lagging phase due to C2; somewhere in the middle, the phases cancel producing zero phase. At the same frequency, the attenuation is minimized. I have chosen C1=C2 and R1=R2 because that makes the computation of frequency of oscillation simple:  $F_o = 1/(2\pi \cdot R \cdot C)$ . The attenuation at the peak is -9.54 dB when I analyze the SPICE plot closely. The amplifier in Figure 2 must have at least 9.54 dB gain



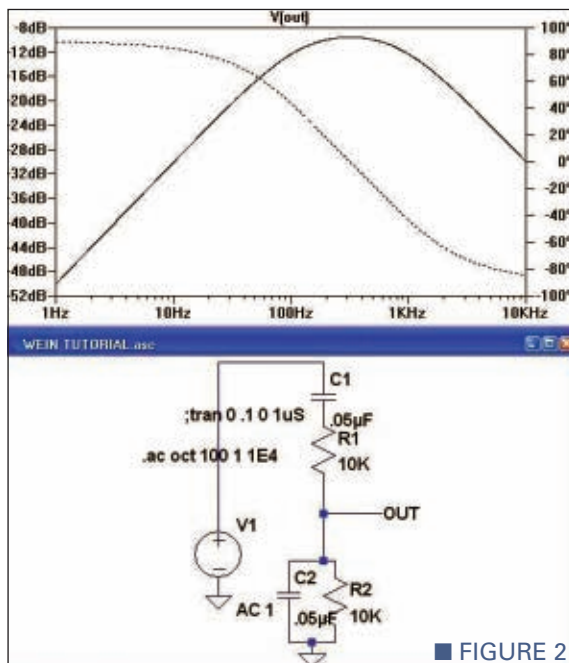
■ FIGURE 1

to oscillate. In Figure 2, the gain is 3 or 10 dB and the circuit is oscillating. In a real circuit, it would not work so well; you have to have gain control to maintain a sinewave. Otherwise, the output will be clipped. In their first product (the 200CD oscillator), Hewlett Packard used the Wein Bridge and in an elegant design, used a lamp for R3. As the signal increases, the lamp gets hotter and increases in resistance, which reduces the gain.

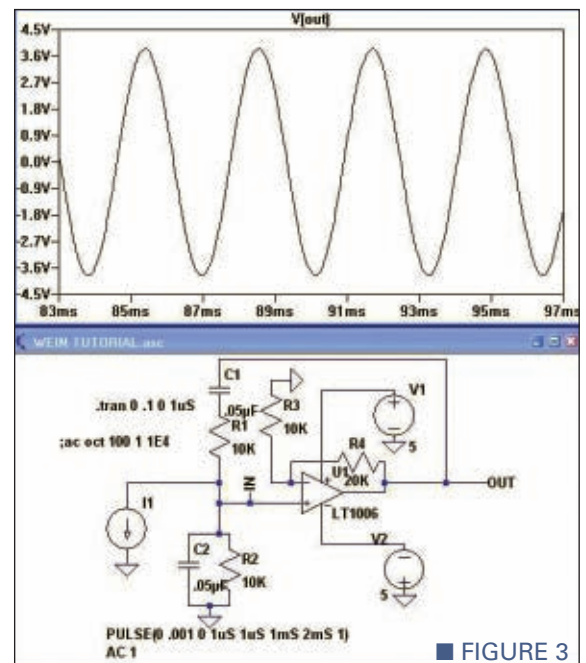
I should explain the current source at the input: oscillators in the

real world start because of noise in the system (even resistance has noise, so any oscillator will start if there is enough gain). The SPICE simulator has no noise, so oscillation will not start unless you give the circuit a poke. The current source is a single pulse that starts the oscillator and then is just an open circuit.

Figure 3 is a frequency sweep of the circuit that shows another reason that the Wein Bridge is popular: The phase change at resonance is so sharp that the frequency cannot deviate without getting far from zero



■ FIGURE 2



■ FIGURE 3

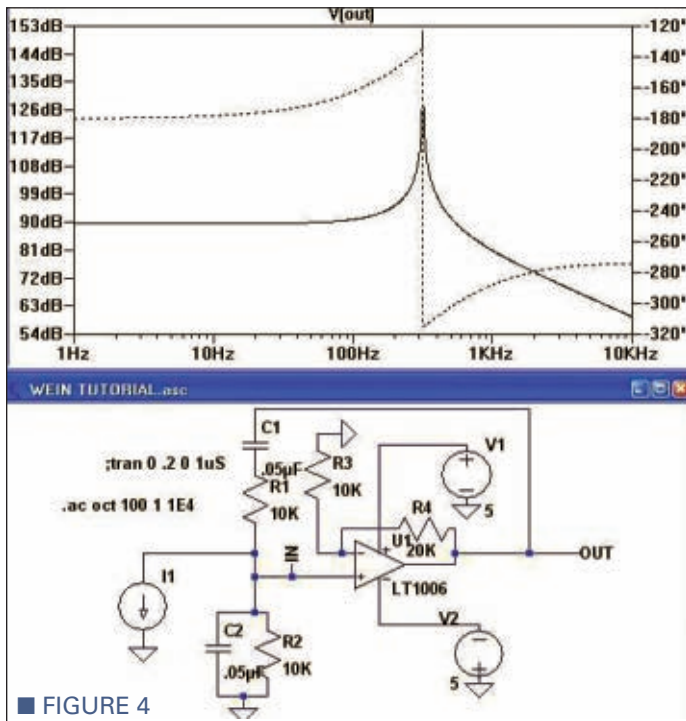


FIGURE 4

phase. Note that the right hand scale is -180 degrees which is also zero degrees. Why the feedback makes the phase change so rapidly is something I have not investigated; I'll leave that to those who have to know.

Figure 4 has R4 reduced to 19K,

making the gain less than needed to oscillate. The circuit rings due to the initial pulse but quickly dies out.

The Colpitts oscillator in Figure 5 is different in that it uses an L-C circuit which has a "flywheel effect." Energy oscillates between the magnetic field

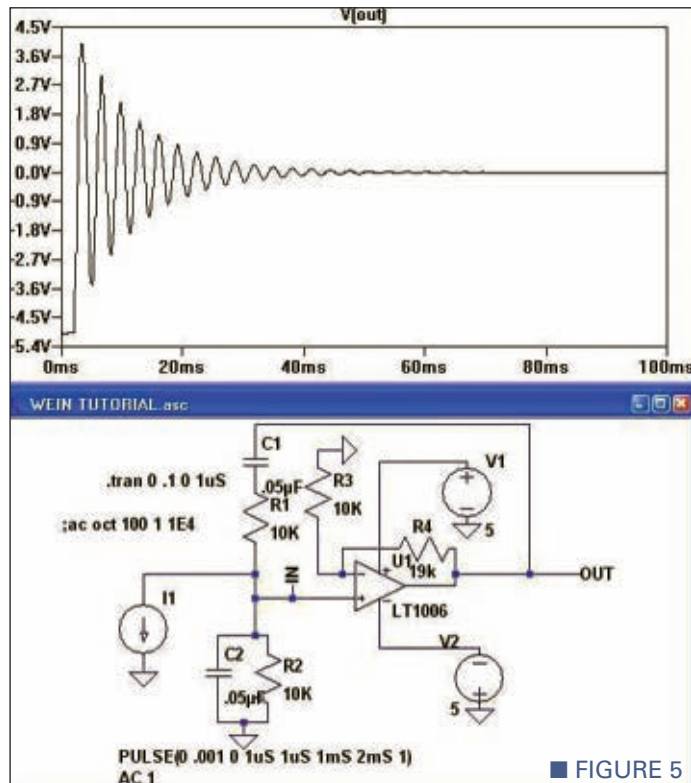


FIGURE 5

and the stored charge, and all the circuit needs to do is poke it regularly to keep it going. Oscillators of this type usually operate class C (the transistor is off some of the time). You can operate class A (transistor

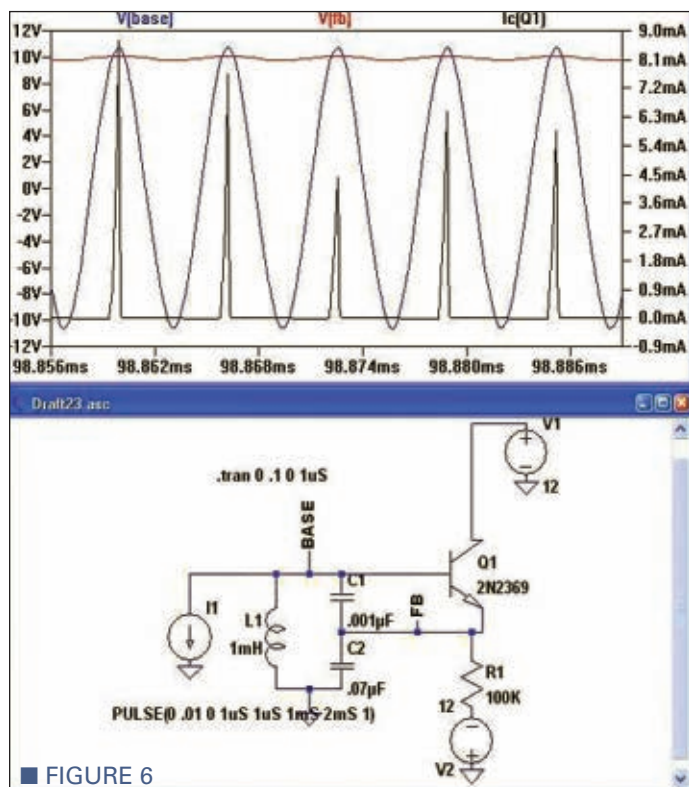


FIGURE 6

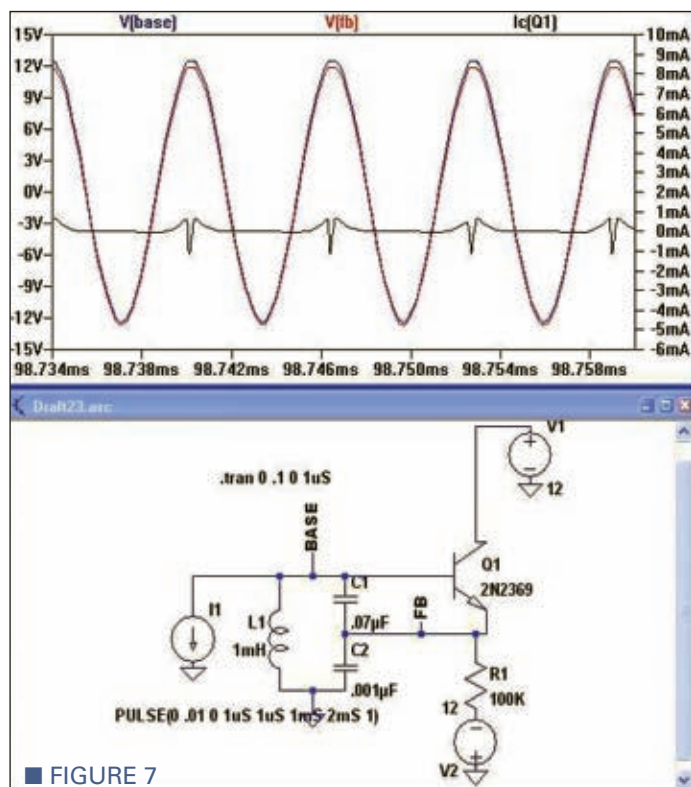


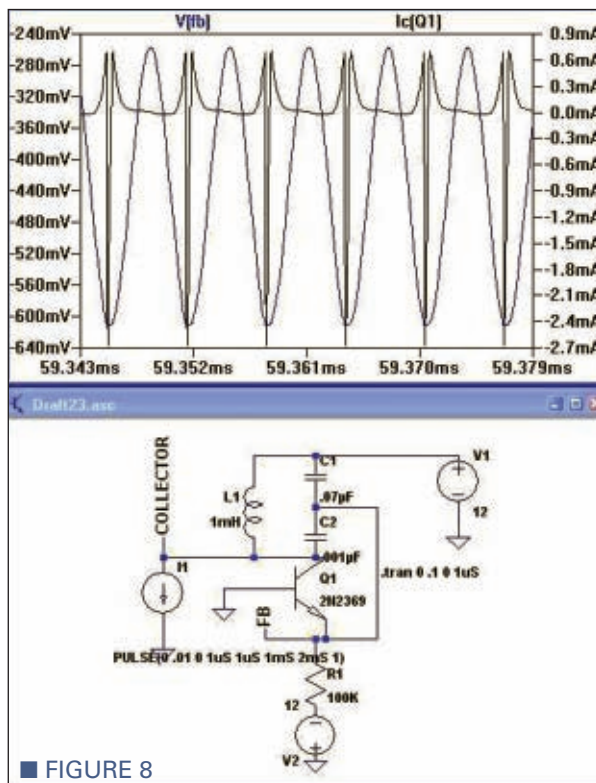
FIGURE 7



conducting all the time) but the waveform will be more distorted and the efficiency lower.

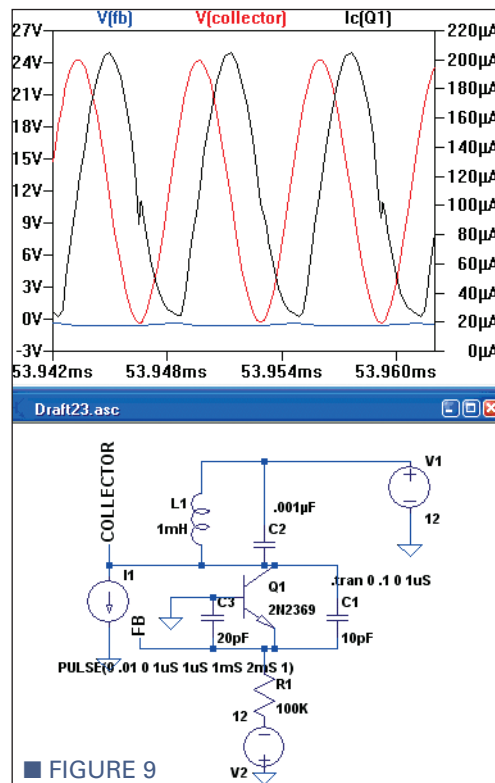
L-C oscillators operate on power gain rather than voltage gain. The feedback must provide enough power to overcome the losses. The ratio of C1/C2 determines the feedback power; a larger C2 gives less power. In Figure 5, I am using a ratio of 1:70; a real circuit would not work with such a large ratio, but this L-C has no loss. Note that V(fb) is at +10 volts which means that the transistor is mostly off (class C). Actually, a real circuit would not go so high because the base-emitter breakdown voltage is about seven volts.

In Figure 6, I have swapped the values of C1 and C2; that puts the



■ FIGURE 8

circuit in class A operation. Note that the collector current shows negative spikes; that is due to the base-collector junction being forward-biased because of increased power being fed back. The emitter



■ FIGURE 9

voltage is following the base because the transistor is conducting all the time.

In Figure 7, I have moved the L-C to the collector circuit. The advantage of that is the breakdown voltage of

## MAILBAG

*On the Current Source for Battery Charger section in the November '08 Q&A column, I got feedback that caused me to think about how to make a precision current source. My solution was to use a rail-to-rail (input and output) op-amp and precision voltage reference to directly regulate the current through a resistor; see Figure A.*

*The LM6492 inputs can go 0.3 volts above and below the power rails; the LM4040 is available in 0.1% to 1% tolerance and 2.048 volts to 10 volts. The minimum current through the LM4040 is 80 microamps which sets the minimum output voltage at 80 millivolts when R3 is 1K. R3 could be larger if a higher minimum output voltage could be tolerated.*

Dear Russell,

I am very interested in all types of DC-DC converters. I liked the subject circuit, however when trying to find the Magnetics Bobbin (#PC-B3515-L1) and Core (OF43515EC), I was unsuccessful. Those parts are not available to

hobbyist (quantity of one) from any of the major suppliers. Please advise.

I also liked the "dead-time" designed into the circuit, but it is a lot of dead time — 1.5 uS out of each cycle with an on time of only 5 uS. I also note other than the turns ratio of the transformer, there is no regulation of the 12 volt output. What I did like was the FET driver IC (I didn't know those kinds of drivers existed). What I didn't like was the fact you used SMD parts when you could have quoted "through-hole" parts. It is not so easy for run-of-the-mill hobbyists (like myself) to deal with SMD parts for one-of-a-kind projects.

I am very impressed with your extensive knowledge of everything electronic!

— Chuck Irwin, Hendersonville, NC

*RESPONSE: My apologies for the delay in answering. I guess I should have said that you have to request a sample from Magnetics, Inc. That is the only way I have gotten cores or bobbins. Magnetics may want to charge shipping to a UPS account. I have established an account with UPS for that reason, although it usually*

*continued ...*

Mailbag continued ...

expires before I need another sample so I have to re-establish it.

The dead-time is 1.3  $\mu$ S out of 5.1  $\mu$ S on time; that is a long dead time. R2 could be cut in half with no problem. That would increase the frequency, so you should increase R1 by the amount that R2 was decreased. Feedback to pin 5 of the 555 could have been used for regulation but I

did not regulate the output because the radio does not care that much about it.

Many of the newer parts are not available as through-hole. In order to stay current, you need to learn how to handle SMD. You can use PNP Blue and a laser printer, or some people laser print onto glossy paper to make the printed circuit board. I have used prepasted wallpaper but have not been able to find any smooth enough lately.

the collector is higher, so a larger voltage swing is possible. Note that the emitter voltage  $V_{(fb)}$  barely gets to -600 mV where the transistor is turned on and at the same time the collector voltage is minimum, so the power dissipated in the transistor is minimized.

Since V1 is a virtual ground, separate capacitors could be used for feedback as in Figure 8. The advantage here is that the circuit can be tuned by C2 and not affect the feedback ratio. Since the transistor has internal capacitance from base to emitter, C3 is not

needed and Figure 9 is the one normally used.

## INFORMATION ABOUT FLAT PANEL TVS

**Q** Do you know of any literature (principles and trouble-shooting) concerning flat panel (LCD and plasma) TVs? To our surprise we couldn't find anything on Amazon, Alibris, or other book dealers. Even Google lacks technical information


about these topics.

Best regards and thank you for your wonderful section.

— Francisco

**A** You have not looked in the right places. Wikipedia has information on both LCD and plasma displays, with references: [http://en.wikipedia.org/wiki/Plasma\\_displays](http://en.wikipedia.org/wiki/Plasma_displays) and [http://en.wikipedia.org/wiki/LCD\\_displays](http://en.wikipedia.org/wiki/LCD_displays).

The service manual for a particular TV should have trouble-shooting information. **NV**



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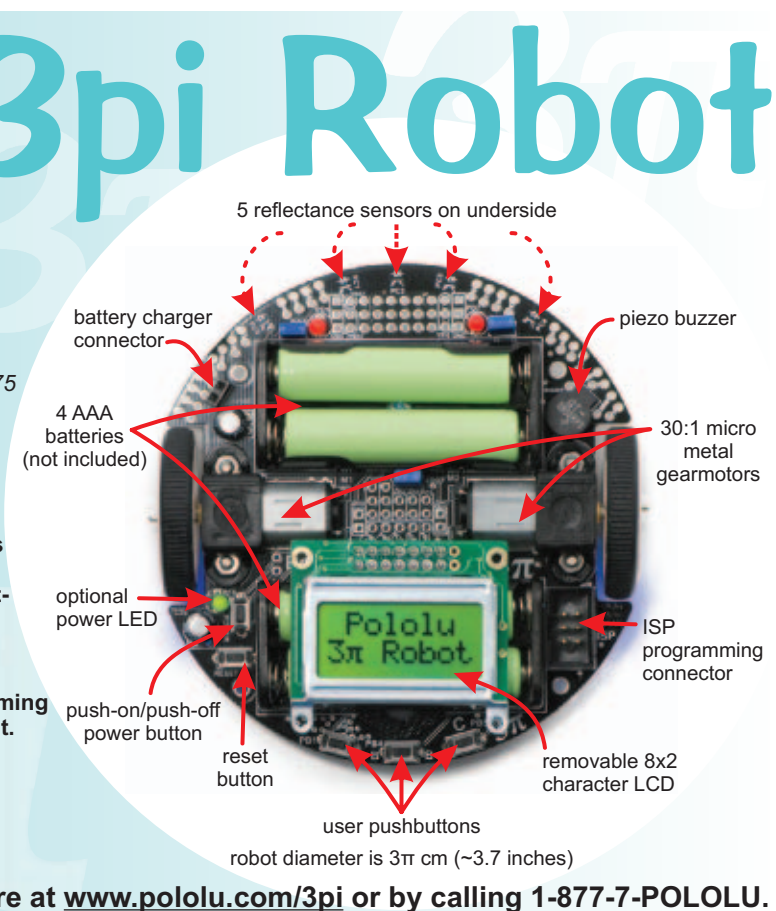
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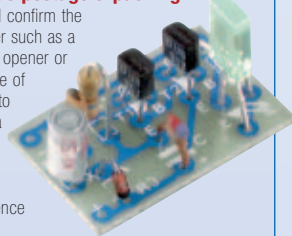


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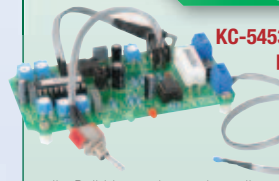
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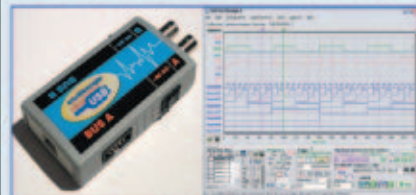
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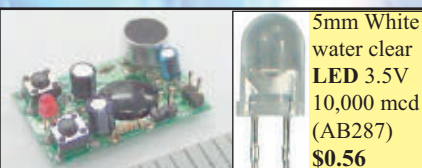
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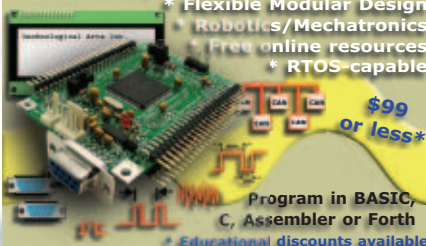


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# INDUCTIVE PROXIMITY SENSORS

BY BEAU SCHWABE

## PART 1

An inductive sensor is one type of proximity sensor which can detect objects without actually touching them. Photoelectric and capacitive sensors are also found in this category. The inductive proximity sensor only detects metallic objects while ignoring all others, and has many industrial uses which capitalize on this feature.

The inductive sensor is a simple device. At the fundamental level, the sensor is a coil of wire with an AC current passing through it. When a metallic object is brought near the coil, it creates a load and the inductance significantly increases. Most non-metallic objects have a negligible effect when it comes to changing the inductance value because the resulting AC magnetic field doesn't "couple" to the coil.

While a capacitor opposes a change in voltage, an

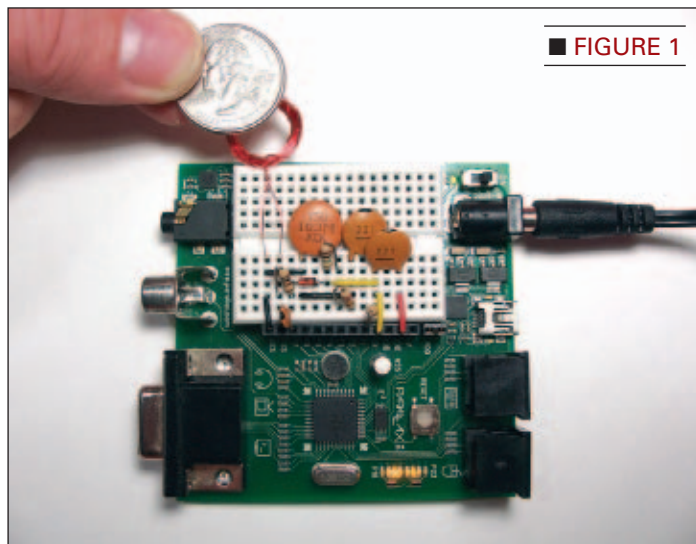
inductor opposes a change in current. When used together, a capacitor and inductor complement each other to form an LC circuit that has a specific resonant frequency. This frequency is determined by the values of the inductor and capacitor. There are two types of LC circuits. The first is called "series resonant" where the capacitor and inductor are placed in series. The other is "parallel resonant" where the capacitor and inductor are — not surprisingly — placed parallel to one another. Series resonant configurations are generally used to amplify voltage, while parallel resonant configurations are used to amplify current. In this project, we will be using a series resonant circuit built on a Propeller demo board to detect the proximity of a metallic object (Figure 1).

## Coil Construction

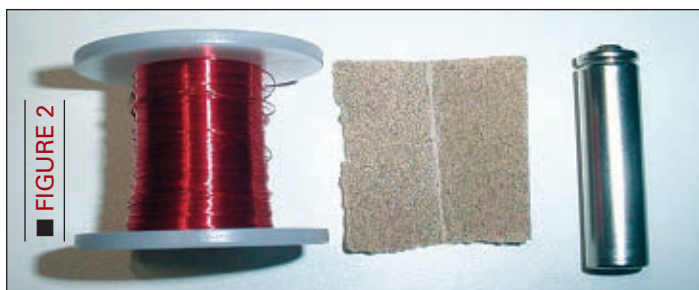
Materials you will need (Figure 2):

- 48 inches of 30 gauge enameled copper wire (RadioShack sells this as the "red" spool in their three-pack of magnet wire)
- 100 grit sandpaper
- 14.5 mm coil-form that you can easily slide the finished coil off of (I used a rechargeable AA battery with the label removed)

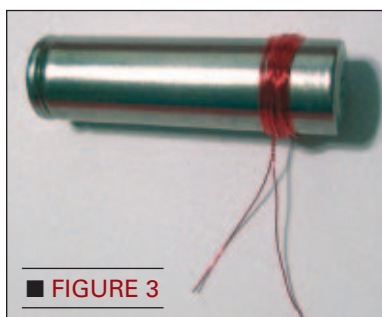
With 48 inches of



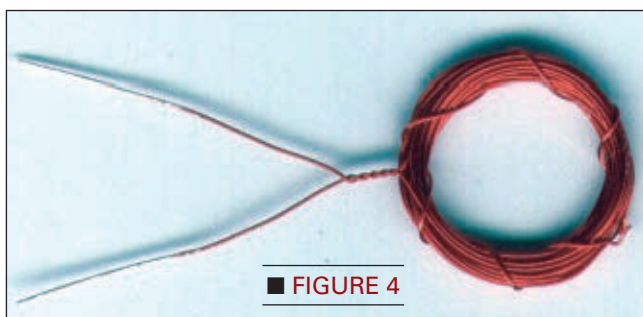
■ FIGURE 1



■ FIGURE 2



■ FIGURE 3



■ FIGURE 4



enameled copper wire, wind 25 turns over the coil-form leaving about an inch of lead length from the coil. Twist both ends together with about five twists (Figure 3). Slide the coil off of the coil form. To prevent the coil from unwinding, cut a scrap 3.5 inch piece of enameled wire from the spool. Wind the scrap piece of wire in a toroid fashion around the coil and twist the ends together trimming off any excess wire you may have when you are done (Figure 4). It should only take five or six toroid loops with the scrap piece of wire to secure a coil of this size.

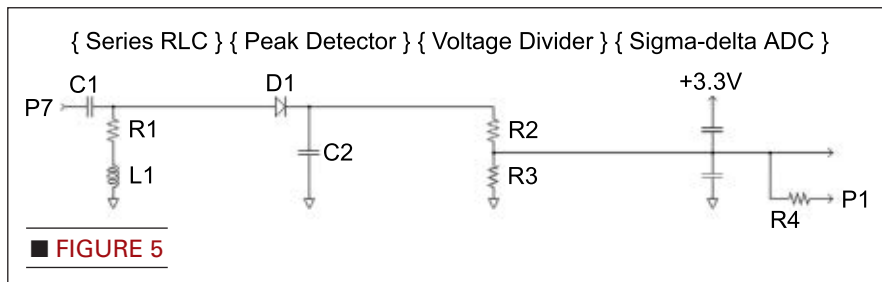
To remove the enamel from the ends of the coil wire, start by cutting a small piece of 100 grit sandpaper about 1.5 inches by 1.5 inches. Fold the sandpaper in half with the sandy face inside. Place the end of the enameled wire inside the folded sand paper, lightly pinch the wire between your thumb and forefinger, and gently pull it along the wire to its end. After a few passes, you will see the red enamel come off, revealing the copper wire beneath. Work around the wire until there is a bright copper area at the end of the wire about a half inch in length.

## Circuit Description

Operation of this circuit has two basic requirements in order for it to function properly. First, a local oscillator of some kind is needed to provide a sweep frequency that will excite the RLC circuit at or near its resonant frequency. Second, there needs to be a detector of some sort to measure the coupling of the circuit. We'll use the Propeller in both roles!

It's helpful to think of this circuit like a radio except that your tuner (the RLC circuit) is fixed to one frequency. The Propeller (radio transmitter) must try all possible frequencies in a sweep pattern to determine if its signal can be "heard" on the nearby radio (the RLC). In order for the Propeller to listen or monitor its own signal, there needs to be a way to detect any changes that happen on the output of the RLC circuit as it is being swept. With a few external passive components (Figure 5), both requirements can easily be fulfilled by using the Propeller chip's unique internal counter capabilities. Each of the chip's eight parallel processors has two counter modules.

One counter can be configured as a free running local oscillator to sweep the frequency, while another counter can be configured as a positive edge triggered detector with an inverted feedback output. The configuration of the second counter serves to function as a sigma-delta ADC (analog-to-digital converter). Question: What the heck is a sigma-delta ADC and why are we using one? A sigma-delta ADC is a type of ADC ideally suited for the input of a microprocessor that can only distinguish the difference between a logic



HIGH "1" or a logic LOW "0" on an input pin.

Sigma-delta ADCs offer a high resolution and low cost solution to this all-or-nothing digital dilemma.

The Propeller doesn't have a built-in ADC, but we can simulate one in software, with the use of a few external passive components. In its simplest form, an ADC requires two pins (P0 and P1 for this demo). One pin is configured as an INPUT (P0), while the other pin is configured as an OUTPUT (P1). The relationship between these pins can be thought of as a simple inverter. If the INPUT detects a HIGH, then the OUTPUT is made LOW; likewise, if the INPUT detects a LOW, then the OUTPUT is made HIGH. The Propeller basically implements this basic inverter function in software through one of its specialized counter configurations. Doing so with a special counter frees the Propeller processor to perform other tasks while the inverter function is allowed to do its thing.

Okay, so how does this ADC work? When you tie the output of an inverter to the input of the same inverter via a resistor (R4), it will tend to migrate the output voltage of the inverter to a voltage level equal to the input threshold voltage. This is because the output pin (P1) constantly creates a signal in the opposite direction from the detected input (P0) value. With the Propeller, this threshold voltage is typically half of the supply voltage. At this point, if we took a measurement by counting the number of 1s vs. the number of 0s, we would see that the ratio would be right at 50% as expected ... since the output voltage is half, or 50% of the supply. By adding capacitors (C3 and C4) which are balanced to the power and ground terminals, a unique charge/discharge circuit is set up with the output (R4 through P1) of the "inverter."

## PARTS LIST

ITEM	DESCRIPTION	SUPPLIER/PART #
□ Platform	Propeller demo board	Parallax/32100
□ C1	10 pF capacitor	Digi-Key/478-3160-ND
□ C2	0.01 $\mu$ F capacitor	Digi-Key/478-3178-ND
□ C3, C4	220 pF capacitor	Digi-Key/478-3168-ND
□ D1	1N914 diode	Digi-Key/1N914ACT-ND
□ L1	30 gauge enameled copper wire	RadioShack/278-1345
□ R1	100 $\Omega$ resistor	Digi-Key/OD101JE-ND
□ R2, R4	1M resistor	Digi-Key/OD105JE-ND
□ R3	220K resistor	Digi-Key/OD224JE-ND

The capacitors help stabilize the result and introduce a charge/discharge delay on the input (P0). It is the mechanism of this charge/discharge delay that allows an external voltage to persuade the charge/discharge ratio to one direction or the other and make its way into the charge/discharge cycle affecting the ratio. The result is a ratio of 1s and 0s that are proportional to the input voltage doing the initial persuading.

Using a series resonant circuit consisting of R1, L1, and C1, the RLC functions as a voltage amplifier when the sweep frequency (provided on P7) is close to the resonant frequency of the RLC circuit. When a metallic object is moved closer in proximity to a coil, the inductance of the coil will increase. This also increases the resonant frequency of the RLC circuit. D1 and C2 form a pseudo “peak detector” for the RLC that will feed a voltage divider. The voltage divider, consisting of R2 and R3, has an approximate ratio of 6.5:1. R4, C3, and C4 make up the sigma-delta ADC hardware.

This application makes use of the indicator LEDs built onto the Propeller demo board. If you are using a different Propeller platform, you will need to connect eight LEDs with 240 ohm series resistors to Propeller I/O pins P16-P23. For an LED wiring diagram, refer to the PropDemoDschem.pdf schematic file on the Parallax website located at [www.parallax.com/Portals/0/Downloads/docs/prod/prop/PropDemoDschem.pdf](http://www.parallax.com/Portals/0/Downloads/docs/prod/prop/PropDemoDschem.pdf).

## Software

The code for this demo “Inductive Proximity Sensor.spin” can be downloaded from the Propeller Object Exchange at [www.obex.parallax.com](http://www.obex.parallax.com). Here are some excerpts:

In the CON section, this code tells the Propeller what Crystal frequency we are using, and that we want to use the PLL to multiply the Crystal frequency by 16.

```
_XINFREQ = 5_000_000    'Propeller Processor
                        'Crystal value (5MHz)
_CLKMODE = XTAL1 + PLL16X 'Set PLL value to X16
                        'to get an 80MHz (5MHz
                        'x 16 = 80MHz) clock
```

In the CON section, this code configures what pins will be used with our hardware.

```
SensePin = 0    'ADC INPUT pin
DrivePin = 1    'ADC OUTPUT pin
FPin = 7        'Frequency Synthesizer
                'OUTPUT pin
```

In the CON section, this code configures the Start Frequency, Stop Frequency, and Sweep Step required for the auto calibration routine.

```
StartFrequency = 8_00_000    'Start Frequency to
                              'Sweep ... 500 kHz to
                              '128 MHz
StopFrequency = 10_000_000   'Stop Frequency to Sweep
                              '... 500 kHz to 128 MHz
SweepStep = 25_000           'Sweep increment used in
                              'auto calibration
```

In the VAR section, we define some variables that we will be using.

```
long
Frequency, FMax, ADCmax, Temp, Scan1, Scan2, Blink, n, Sample
```

Auto calibration main loop:

```
cognew(@asm_ADC, @Sample) 'launch Sigma Delta ADC
                          '; uses CTRA

Fmax~                      'Clear Fmax
ADCmax~                   'Clear ADCmax
repeat Frequency from StartFrequency to
StopFrequency step SweepStep 'Sweep frequency

    Synth(FPin, Frequency) 'set oscillator ; uses
                          'CTRB
    waitcnt(cnt+clkfreq>>10) 'Delay ; Allow ADC to
                          'settle
                          'approx 1/1000th of a
                          'second

    if Sample > ADCmax      'Detect 'peak' voltage
                          'value from ADC
        ADCmax := Sample   'this will be the
                          'resonant frequency
        Fmax := Frequency  'of the RLC
```

DEMO program main loop:

```
Synth(FPin, Fmax)         'set the oscillator to
                          'the resonant frequency
                          'of the RLC circuit ;
                          'uses CTRB

dira[16..23] ~~          'Set I/O direction of
                          'LED's to output

repeat                   'Main Loop

    Temp := Sample        'Read current ADC value

    Scan1 := Temp / 412    'Set COARSE LED scale
                          'as Scan1:
                          'Maximum ADC value is
                          '3300 (set below)
                          '....so 3300 / 8 Leds =
                          '412

    outa[16..23] := |< Scan1 'Turn on 1 of 8 LED's
                          'based on ADC value

    Scan2 := (Temp - (Scan1 * 412))/51
                          'Set FINE LED scale as
                          'Scan2:

    ++                  'Used for blinking LED ; increment n
    if n > 2500          'if n > 2500 then clear
                          'n, and toggle
        n := 0           'Blink variable
        Blink := 1 - Blink

    outa[23..16] |= (|< Scan2)* Blink
                          'Turn on 1 of 8 LED's
                          'based on ADC value
```

Subroutines to set synthesizer frequency:

```
PUB Synth(_Pin, Freq) | s, d, ctr, frq
    Freq := Freq #> 500_000 <# 128_000_000
                          'limit frequency range

    ctr := constant(%00010 << 26) '..set PLL mode
    d := >|((Freq - 1) / 1_000_000) 'determine
    'PLLDIV
```



```

s := 4 - d           'determine shift
ctr |= d << 23       'set PLLDIV

FRQB := fraction(Freq, CLKFREQ, s) 'Compute FRQB
                                     'value
CTRB := ctr | _Pin   'set PINA to complete
                                     'CTRB value
DIRA[_Pin]~~        'make pin output

PRI fraction(a, b, shift) : f
  if shift > 0
    a <<= shift      'if shift, pre-shift a
                     'or b left
                     'to maintain significant
                     'bits while
  if shift < 0
    b <<= -shift     'insuring proper result
  repeat 32          'perform long division
                     'of a/b
    f <<= 1
    if a => b
      a -= b
      f++
    a <<= 1

```

Assembly subroutine to start sigma-delta ADC:

```

DAT
asm_ADC      org
or           dira,DrivePinMask 'make DrivePin
                                     'an output

movs        ctra,#SensePin
movd        ctra,#DrivePin
movi        ctra,#%01001_000 'POS W/FEEDBACK
                                     'mode for CTRA
mov         frqa,#1

mov         count,cnt          'prepare for
                                     'WAITCNT loop

:loop
add         count,cycles

mov         phsa, #0           'clear PHSA
waitcnt     count,cycles      'wait for next
                                     'CNT value
mov         _sample,phsa      'move PHSA into
                                     'sample
wrlong      _sample,par       'write sample
                                     'back to Spin
                                     'variable
                                     '"sample"
jmp         #:loop            'wait for next
                                     'sample

cycles      long      3300      'VDD Voltage
                                     'level (mV)
DrivePinMask long      |< DrivePin 'output mask
count       long      0
_sample     long      0

```

## What to Do? What to Observe?

There are two modes of operation with this demo. When you connect the circuit and run the code without any metal in proximity to the sense coil, you should see two illuminated yellow LEDs on the Propeller demo board, with the leftmost LED solid and the rightmost LED blinking (assuming the LED side of the board is closest to you). If this is not the case, then re-check your wiring and make sure that all of your connections are secure.

With both modes, the sensing distance is about 5-10 mm from the coil. If you have a metal object such as a quarter, move it slowly towards the coil and you should

see the blinking LED move from right to left. This is the "fine movement indicator" (FMI). As you continue to move the metal object even closer to the sense coil, you should notice that the solid LED or the "coarse" movement indicator" (CMI) will start moving from left to right, and the FMI has wrapped back around to the right side to begin the process all over again. Thus, each time that the FMI wraps around from right to left, the CMI advances one position to the right. This LED implementation is a compact way to provide visual feedback representing several different data positions from only eight indicator LEDs.

The second mode of operation involves running the code with metal already in close proximity to the sense coil. The LED indicators should still be the same as mentioned above with two illuminated yellow LEDs on the demo board. This time, by removing the metal object you should see the FMI (the blinking LED) move from right to left. As you continue to remove the metal object even further away from the sense coil, you should notice that the CMI (the solid LED) will start moving from left to right, and the FMI has wrapped back around to the right side to begin the process all over again.

The reason for why there are two different operation modes will be explained in further detail in Part 2, where we will use multiple coils in a differential sensor approach. For now, have fun with this and enjoy trying different coil sizes and shapes to see what you can come up with on your own. **NV**

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# MAKIN' MIDI: mistralXG

## A USB CONNECTED, PIC-BASED MIDI SYNTHESIZER

### PART 2: Let's get technical!

BY STEVE RUSSELL

**Welcome back! Last time, I described how the user interacts with mistralXG to switch MIDI streams to the synthesizer and to control the various user options. This month, I'll lift the hood on the design to show you how the hardware and software work together to make mistralXG do its thing.**

### Guided Tour of the Hardware

First, let's take another look at the mistralXG block diagram (Figure 1).

Comparing this with the circuit schematic (Figure 2), we can identify the major functional areas of the design. The detail may be too fine to read in the magazine, so I recommend getting the schematic from the *Nuts & Volts* website ([www.nutsvolts.com](http://www.nutsvolts.com)) and opening it with the free version of Eagle ([www.cadsoft.de/freeware.htm](http://www.cadsoft.de/freeware.htm)) so you can explore it more fully. In the meantime, I'll give you an overview.

The hardware is relatively simple. As you can see in the schematic, there are only a handful of chips: the PIC18F2550, three 74ALS00s, a couple of dual op-amps, and an opto-isolator for the MIDI input. The WX IN input is for a wind controller; as well as receiving the MIDI data, it provides power to the controller. Make sure anything you attach to this port is suitable and won't be damaged

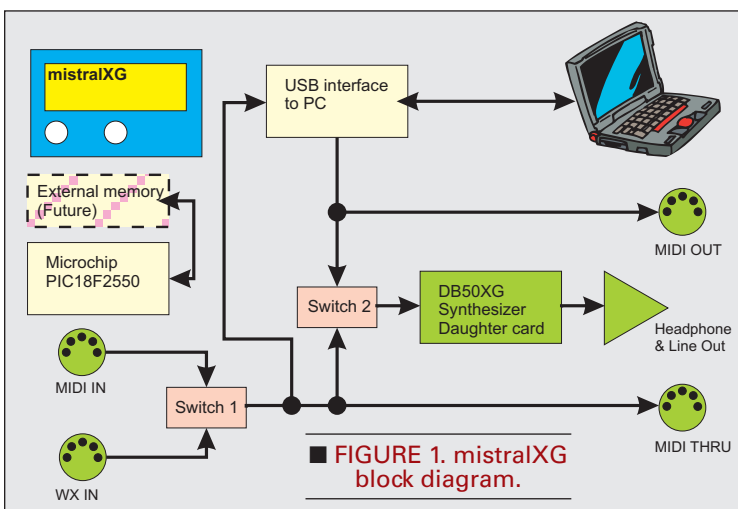
by the voltage present at the connector. If you don't need this input, you can replace it with a second standard MIDI IN port by duplicating the other MIDI IN circuit.

Areas 1 and 2 implement Switches 1 and 2 in the block diagram, respectively. Area 3 provides the control to enable and disable MIDI THRU and MIDI OUT. These controls use three 74ALS00 logic chips, selected to give a fast response with low power consumption. Outputs from the MCU control these features.

Area 4 contains the MCU and its oscillator. The PIC18F2550 supports many oscillator configurations. I chose a 4 MHz crystal, running the internal clock at 48 MHz as needed by the USB port. Each MCU instruction takes four CPU clocks, giving a cycle time of about 83 ns. To use a different crystal, you'll have to modify the MCU's configuration settings (`mxg_config.c`). Q1 is a transistor that uses pulse width modulation to control the brightness of the LCD backlight.

The DB50XG daughter card is attached via connector WB1 (Area 5). The pin numbering used on WB1 matches the numbering printed on the DB50XG.

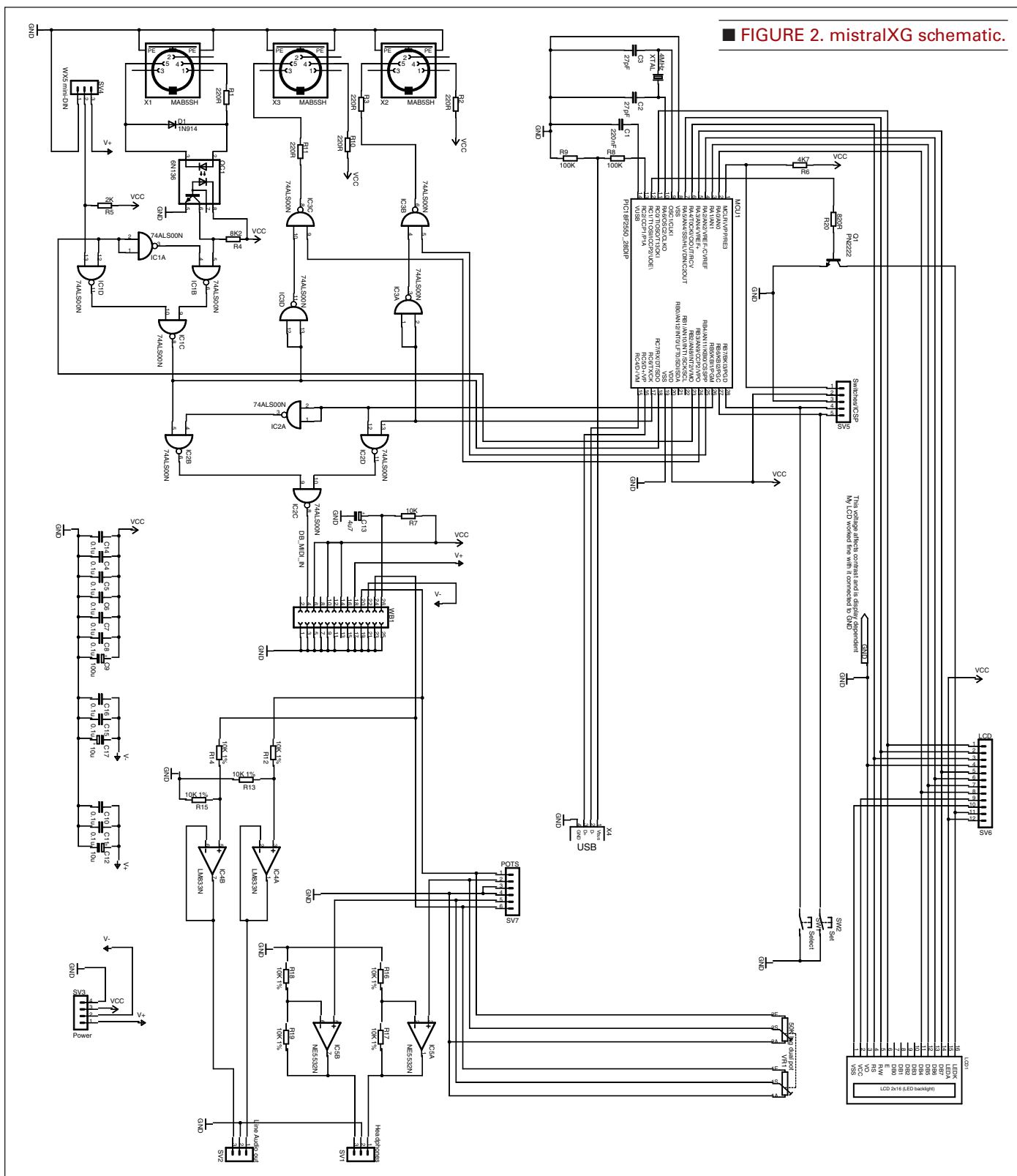
The outputs of the DB50XG are protected from an inadvertent short-circuit by a pair of op-amp buffers (IC4A&B). A second pair of op-amps (IC5A&B) provides stereo outputs for headphones; the volume is controlled by a 50K dual-gang pot. These amplifiers are in Area 6 in Figure 2. The DB50XG outputs about 3V peak-to-peak, so I've included a way to attenuate the line outputs. If no attenuation is required, R12 and R14 should be replaced with plain wire links. As shown, they are 10K resistors and halve the output voltage (-6 dB). You can select an appropriate value to give the attenuation you need, but I wouldn't go above about 50K for each of these two resistors — use 1% components to give good stereo matching.





The headphone amps can also be tweaked. As shown, they give a gain of 2 (+6 dB — about 6V peak-to-peak), but I found a gain of 1 (leaving resistors R16 and R18 out of the circuit altogether) sufficient. I don't recommend increasing the gain beyond 2, to minimize the risk of distortion.

Area 7 shows the LCD, the two pushbuttons, and the volume control. Header pins for these are included in the circuit so that they can be connected via flying leads. The USB connector is also here. This, and the MIDI inputs and outputs could be either mounted on the



circuit board or panel-mounted, as you prefer.

## Building the Circuit

I used a breadboard for the prototype, but techniques such as stripboard, custom PCB (printed circuit board), etc., could also be used. Unfortunately, the free version of Eagle only creates circuit boards up to 80x100 mm (which is too small), so there is no PCB design at present.

Care should be taken when laying out the oscillator circuitry. Keep track lengths short and position the crystal and its capacitors close to the MCU. Also keep the analog (op-amps) area separate from the logic to avoid digital noise on the analog signals.

The capacitors shown to the bottom right of the schematic are for general decoupling. Position a 0.1  $\mu$ F capacitor as close as possible to each chip. These provide good high frequency decoupling. The larger value polarized capacitors are for bulk decoupling and are not so critical in their placement.

Construction is straightforward. Anyone with basic electronic skills (soldering, reading a schematic, and so on) will be able to put the unit together.

## Power

The completed circuit needs ground, +5V, +12V, and -12V power supplies;  $\pm 12$ V are only needed if the daughter board is used. If not, the op-amps can also be omitted and only +5V is required.

■ **TABLE 1. Power supply measurements.**

Condition	+5V supply	+12V supply	-12V supply	Notes
No daughter board, backlight off.	50 mA	Not needed	Not needed	
No daughter board, backlight on max.	250 mA	Not needed	Not needed	
Daughter board playing music, backlight on max.	600 mA	25 mA (see note)	25 mA	My wind controller draws an additional 50 mA from the +12V rail.

Module name	Function	Module name	Function
mxg_config.c	MCU configuration	user/user.c	Main user function
io_cfg.h	MCU I/O pin configuration	user/mxg_xlcd.c	LCD functions
main.c	main() function	user/mxg_usart.c	EUSART functions
autofiles\usbds.c	USB descriptors	user/mxg_umsm.c	USB to MIDI conversion
usb\usbdefs\usbdefs_std_dsc.h			
system\usb\usbmmmap.c	Microchip USB Firmware Framework files	user\mxg_musm.c	MIDI to USB conversion
system\usb\usbdvr\usbdvr.c		user\mxg_msgs.c	Messages
system\usb\usbctrlr\usbctrlr.c	usbms.c is the modified usbgen.c from the framework	user\mxg_iface.c	User interface functions
system\usb\usb9\usb9.c		user\mxg_error.c	Error functions
system\usb\class\ms\usbms.c			
system\interrupt\interrupt.c		user\mxg_eeprom.c	EEPROM functions

Table 1 shows the current drawn under various conditions to allow you to tailor your power supplies depending on what you choose to include in the design.

## Software: The Brains Behind mistralXG

mistralXG's software is written in C, using the Microchip C18 compiler (student edition). The compiler and MPLAB integrated development environment (IDE) are both available as free Windows downloads from the Microchip website.

The individual modules are listed in Table 2. Each C module is shown with its directory path relative to the main.c module and a brief description of its function. A matching \*.h file for each \*.c module contains definitions used in the other modules. There are some additional \*.h files included with the framework to control things such as how the MCU senses when the USB port is connected to the PC.

## Framework File Changes

Several sample applications are included with the USB Firmware Framework. mistralXG is based on the Generic sample with a few simple text changes to reflect that a MIDI streaming interface is being used. The framework comprises all modules in Table 2, with the exception of those in the user\ directory.

Many framework files are used without change, but a few have to be tweaked. For example, io\_cfg.h defines the pinout for Microchip's standard evaluation boards, so this

was modified to match mistralXG's I/O. Perhaps the trickiest file holds the USB descriptor (auto files\usbds.c). This file and its associated header file (usb\usbdefs\usbdefs\_std\_dsc.h) define the information that is presented to the PC during enumeration. Getting them right is quite difficult — I managed to blue screen my Windows XP system several times while experimenting with mistralXG's descriptors. It's likely you'll need to make descriptor changes if you plan to extend the features of mistralXG. I recommend reading the relevant USB specifications carefully before starting!

A couple of important pieces of information are held in the descriptors. These are the vendor ID and product ID (VID and PID). The PC uses these to identify a device during enumeration. mistralXG has its own unique VID/PID combination.

## mistralXG Application Firmware

The main() routine (Example 1) first initializes the system by calling the framework initialization

code which, in turn, calls the initialization routines for the application modules. It then loops around servicing the user

■ **TABLE 2. Program structure and module function.**



```
void main(void)
{
    InitializeSystem();
    while(1)
    {
        USBTasks();    // USB Tasks
        ProcessIO();
    }
}
```

#### ■ EXAMPLE 1. main() routine.

routines in `ProcessIO()` and `USBTasks()`, which handles USB housekeeping routines such as disconnecting and reconnecting to the PC. The USB code is not interrupt driven. `ProcessIO()` must execute promptly, otherwise the USB interface will fail. I'll come back to this point later.

## Interrupts Provide the Heartbeat

The heart of the `mistralXG` code is the interrupt routine (`interrupt.c`) which handles three types of events: a timer running every 1 ms; and receive and transmit interrupts from the `EUSART`, generated by the incoming and outgoing MIDI streams.

The timer interrupt manages a number of things:

- A display refresh timer that updates the display every 100 ms.
- A display timeout timer that returns the display to the Home Screen after a few seconds.
- The Running Status injection timer that ensures a MIDI command/status byte is sent at least every 250 ms.
- Switch debouncing to prevent spurious input from the pushbuttons.

MIDI data to and from `mistralXG` are handled by the interrupt routine and placed in buffers for transmission to the PC and `synth`.

## Keeping Everything Going — user.c

There are three main routines in `user.c`. `UserInit()` handles initialization of the various user routines and is responsible for configuring the various peripherals. Next in line is `ProcessIO()`, discussed later, and finally there is `ServiceRequests()`, responsible for the user data flowing over the USB.

## ProcessIO() — the scheduler

If interrupts form `mistralXG`'s heart, `ProcessIO()` is the brain. This routine keeps everything in sync and on track. A pseudo-code skeleton of its function is shown in Example 2.

If you look at the source code, you'll see that there is a lot of additional fine detail to make sure that everything works as it needs to, but the pseudo-code captures the essence of the routine's function, and I'll take you through this step-by-step:

- It first checks whether a MIDI byte has been received by the `EUSART`. If so, `processNextByte()` (`mxg_musm.c`)

```
void ProcessIO(void)
{
    if(MIDI data received) processNextByte();
    if(buttons changed)
        handle the button press;
    if(data to write to EEPROM and it's
       not busy) write data to EEPROM;
    if(display timeout occurred)
        switch to Home Screen;
    if(display refresh timer complete)
        refreshDisplay();
    if(WritesToLCDPending and LCD not busy)
        nextChar();

    // User Application USB tasks
    if(USB not connected)
        disable MIDI to USB;
    else {
        ServiceRequests();    // USB is active
    }
} //end ProcessIO

void ServiceRequests(void)
{
    if(incoming MIDI data ready)
        send it to the PC via USB;
    if(USB-MIDI data packet ready)
        send it to the synth/MIDIOUT;
} //end ServiceRequests
```

#### ■ EXAMPLE 2. The `ProcessIO()` and `ServiceRequests()` user routines.

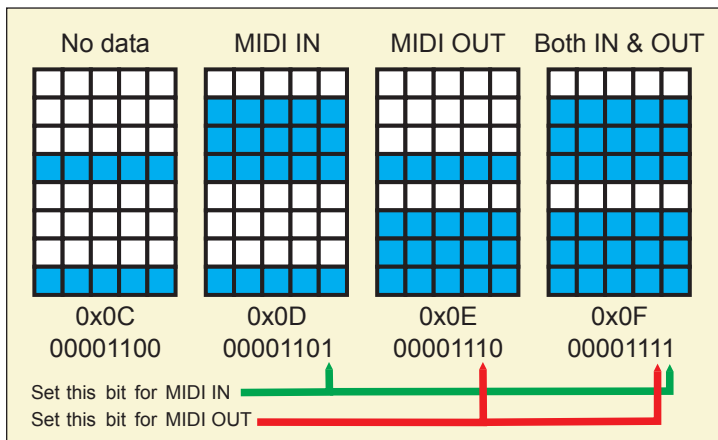
- handles it by building it into a USB-MIDI packet. A complete MIDI command message of one to three bytes is combined into a single packet, with up to 16 packets being sent in a single USB transfer.
- Changes to the two pushbuttons are checked for and handled in `mxg_iface.c`.
- If the user has changed an option, its setting is saved in the MCU's EEPROM (`mxg_eeprom.c`). Writes to the EEPROM take several milliseconds so they are scheduled and processed when the hardware is available.
- If the display timeout timer has expired, the display is switched back to the Home Screen (`mxg_iface.c`).
- If the display refresh timer has expired, a display refresh is scheduled (`mxg_iface.c`).
- Some display updates can take well over 1 ms, so these are scheduled to occur when the hardware is available (`mxg_iface.c`).

If the USB port is connected, `ServiceRequests()` is then called to handle the application's USB transfers, doing so in two stages:

- It first checks whether any incoming MIDI data has been assembled into packets for the PC and, if so, sends them.
- It then checks for received USB-MIDI packets and, if so, transfers extracted MIDI data to the transmit buffer where the interrupt routine picks them up and sends them out to the `synth`.

## Timing is Critical

I've used the word *scheduled* several times in the



■ FIGURE 3. MIDI monitoring user-defined characters.

code description. This is important and I'll use the LCD to illustrate why. Microchip provides a library of routines for driving an LCD display with its C18 compiler, but it quickly became obvious that I couldn't use it. This is because many of the routines wait for the display to finish executing a command before returning control to the calling routine. As mentioned earlier, if ProcessIO() holds things up for too long, the USB code times out and fails.



■ FIGURE 4. mistralXG Home Screen.

To avoid this problem, the application code is written using *non-blocking* routines — that is, routines that do not wait for an event to complete. I achieved this by setting flags to indicate when actions are pending and waiting until the hardware is idle before executing them. It takes 34 writes to completely update the screen. They are scheduled to start every 100  $\mu$ s and ProcessIO() performs one write each time it executes and the display isn't busy. Using this technique, the 34 writes take just a few milliseconds.

## Monitoring MIDI Channels

The error flags were originally on the Home Screen. I decided that it would be a better use of the display to monitor MIDI data, but wasn't sure how to do it with the limited display resources. Figure 3 shows how I solved the problem.

The LCD controller chip supports eight user-defined characters. By defining the four characters shown, a single bit change indicates that a channel has received data. Sixteen characters representing channels 1-16 are held in a buffer. After the character for a particular position is written to the display, it is set to the "no data" state. Then, as each MIDI IN or OUT packet is processed, the appropriate bit is switched on, changing the character code to indicate data traffic IN and/or OUT. This is reflected on the display at the next refresh. The overhead to do this is low as the channel number is easily obtained from the MIDI streams, and the MCU has instructions that flip a single bit. You can see the monitor in action in Figure 4.

## PARTS LIST

PART	VALUE	DEVICE
□ C1	220 nF	C75/3
□ C2, C3	27 pF	C5/3
□ C4 - C8	0.1 $\mu$ F	C5/3
□ C9	100 $\mu$ F	CPOL-EUB45181B
□ C10, C11	0.1 $\mu$ F	C5/3
□ C12, C17	10 $\mu$ F	CPOL-EUB45181B
□ C13	4.7 $\mu$ F	CPOL-EUB45181B
□ C14 - C16	0.1 $\mu$ F	C5/3
□ D1	1N914	1N914
□ IC1 - IC3	74ALS00N	74ALS00N
□ IC4	LM833N	LM358N
□ IC5	NE5532N	LM358N
□ LCD1	LCD_2X16_SIL	HY-1602F
□ MCU1	PIC18F2550	
□ OC1	6N136	6N136
□ Q1	PN2222	2N2222TO92
□ R1 - R3	220 $\Omega$	R-EU_0207/10
□ R4	8.2K	R-EU_0207/10
□ R5	2K	R-EU_0207/10
□ R6	4.7K	R-EU_0207/10
□ R7	10K	R-EU_0207/10
□ R8, R9	100K	R-EU_0207/10
□ R10, R11	220 $\Omega$	R-EU_0207/10
□ R12 - R19	10K, 1%	R-EU_0207/10
□ R20	820 $\Omega$	R-EU_0207/10
□ SV1	Headphones	MA03-1
□ SV2	Line audio out	MA03-1
□ SV3	Power	MA04-1
□ SV4	WX5 mini-DIN	MA03-1
□ SV5	Switches/ICSP	MA05-1
□ SV6	LCD	MA12-1
□ SV7	Pots	MA06-1
□ VR1	50K log dual	PC16D
□ WB1	WAVEBLASTER	
□ X1 - X3	MAB5SH	MAB5SH
□ X4	PN61729	
□ XTAL	4 MHz	CRYSTALHC49U-H

## TOOLS FOR CONSTRUCTION

Construction is straightforward; just make sure you get the chips and polarized capacitors the right way 'round. Programming the device requires a suitable device programmer to install the bootloader. Once that is installed, the chip can be programmed with the mistralXG code via the USB port.

A quick Google search found many sites from which you can purchase relatively cheap programmers and programmer kits (<\$100, some much less). Probably the best solution is one of the programmers/debuggers from Microchip. The PICKit2 is a good value at less than \$50 for a starter kit that includes an evaluation board.

Alternatively, I may be able to provide a pre-programmed PIC18F2550 for a nominal charge. Anyone interested should first contact me at [pic.projects@grapevyne.com](mailto:pic.projects@grapevyne.com) to discuss availability.



## Programming mistralXG's MCU

Microchip provides a bootloader for the PIC18F2550 MCU. This sits in the first 2K of program memory and lets you reprogram the chip over the USB interface. I modified this to suit the hardware configuration used by mistralXG. The bootloader hex file (MistralBoot.hex) needs to be burned into the MCU. The pushbutton connectors have been arranged to double-up as the In-Circuit Serial Programming (ICSP) interface, so this could be used if you have a suitable programmer.

With the bootloader installed, holding the Select button down as you switch on puts mistralXG into programming mode. You can then program the device with hex files from the PC using Microchip's PDFSUSB.exe utility (included with the firmware framework). Use the utility to program in mistralXG.hex and then cycle the power (leaving the pushbuttons alone) to see the Splash Screen and start playing with your own mistralXG!

## Conclusion

I had great fun developing mistralXG and learned a lot about USB and PIC peripherals. I hope you feel as inspired to experiment as I did

Robert Lang's MIDI-nator was the initial inspiration for me to start work on the design.

Thorsten Klose ([www.ucapps.de](http://www.ucapps.de)) was generous in giving his expertise to answer some technical MIDI-USB questions I had at the outset of the project, for running my MIDI-USB implementation through his test suite, and for the suggestion to add what I've called an injection timer to the running status code.

## TOOLS FOR DEBUG

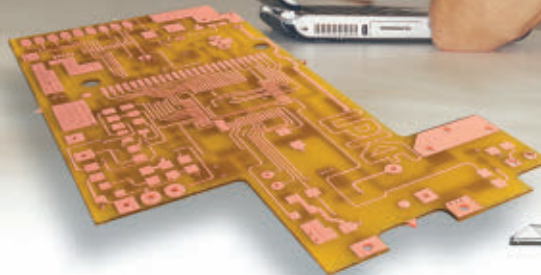
A multimeter is handy for checking voltages and it is useful to have access to an oscilloscope to check what various signals are doing. As long as you've not made any assembly errors, mistralXG should just burst into life when you apply power. If that doesn't happen, you'll need to be able to check that the oscillator is running and the MCU has reset correctly. The Microchip programmer/debugger tools are invaluable in helping you to do this.

and build a mistralXG of your own or put the code to use in some other personal project.

I plan to continue to enhance the project over time. One plan is to add external storage to the design using the SCL and SDA pins on the MCU — these are not used at the moment. I may also update the code to use a later version of the USB Firmware Framework. I'll post any new developments on my website ([www.grapevyne.com/pic.projects](http://www.grapevyne.com/pic.projects)). **NV**

Steve can be contacted via email at [pic.projects@grapevyne.com](mailto:pic.projects@grapevyne.com).

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# WIND YOUR OWN TRANSFORMER AND BUILD A DC-TO-DC CONVERTER

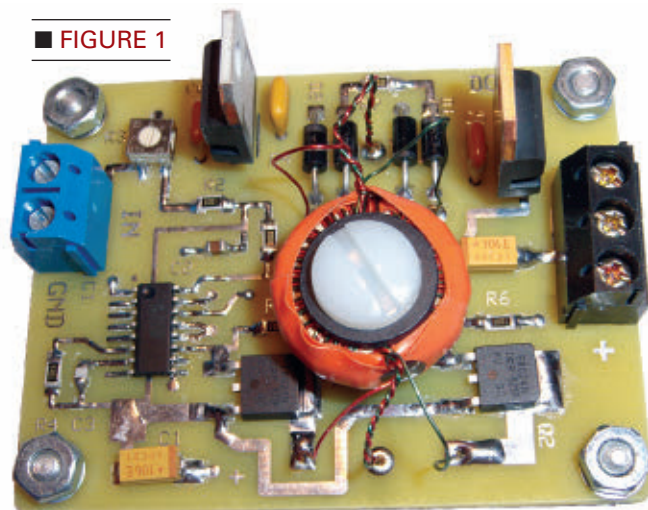
BY JIM STEWART

With switch-mode projects, there's always the problem of where to obtain inductors and/or transformers with the necessary specifications. Parts can be hard to find and expensive. So why not "roll your own?" In this project, we will design and wind a transformer and use it to get +12V and -12V from a 9V battery with the DC-to-DC converter shown in Figure 1.

**M**any hobbyists who look into designing transformers go away thinking it's too hard. There are two reasons for that. First, magnetic material is non-linear, which leads to some arcane equations. Second, there's a profusion of magnetic terminology. There's *one* set of magnetic parameters, but two sets of units to describe them: cgs (centimeter-gram-second) and SI (Standard International). A third set is English units — is obsolete. We use SI units, but a conversion table is provided.

The switching circuit in this project is bare-bones.

■ FIGURE 1



There's no feedback between output voltage and the control IC. We kept it simple because its main purpose is to allow the builder to experiment with winding transformers.

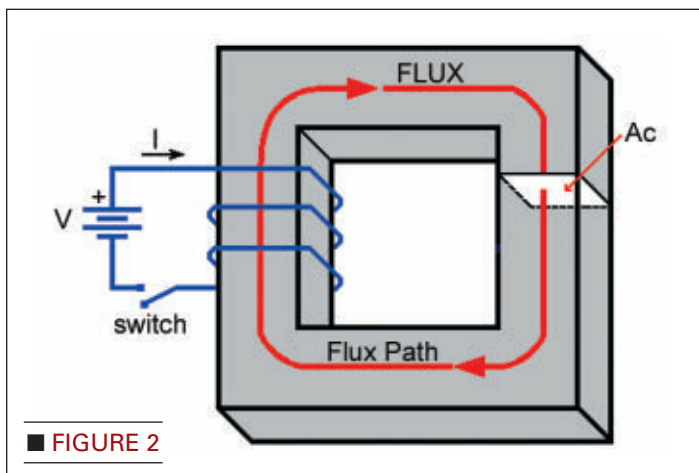
## Magnetics: MMF and Flux

Once it was thought that magnetism and electricity were separate things. They're not. Magnetism is caused by quantum electron-spin and by the relativistic effects of current in a conductor. But let's keep it simple.

We start with *magneto-motive-force* (mmf) and *magnetic flux* ( $\Phi$ ). Wrap a coil of wire around a steel core and put current through it (Figure 2). You get  $\text{mmf} = N \times I$  where  $N$  is the number of turns of wire and  $I$  is the current. The mmf causes flux to flow through the core. We can write Ohm's Law for magnetic circuits:  $\Phi = \text{mmf}/\mathfrak{R}$  where  $\mathfrak{R}$  is the *reluctance*.

Resistance depends on three things: the length of the resistive material ( $l$ ), the area of its cross-section ( $A$ ), and its resistivity ( $\rho$ ):  $R = \rho(l/A)$ . Length and area can change, but the resistivity of a material is constant.

Reluctance has a similar equation:  $\mathfrak{R} = l_f/A_c$  where  $l_f$  is the flux path length,  $A_c$  is the core's cross section area, and  $v$  is the material's reluctivity. The inverse of reluctance is more commonly used:  $1/\mathfrak{R} = \mu (A_c/l_f)$  where  $\mu = 1/v$  is *permeability*.



■ FIGURE 2



## Permeability, Magnetizing Force, and Flux Density

Like resistivity, permeability is a property of magnetic materials like iron. Unlike resistivity, permeability is *not* constant; it changes with flux. Actually, it changes with *flux density* (B).

Flux density is  $B = \Phi / A_c$  and magnetizing force is  $H = \text{mmf} / l_r$ . Since  $\mu$  changes with B, the B-H graph is non-linear as in Figure 3.

Permeability is the slope of the B-H curve at a specified value of B:  $\mu = \Delta B / \Delta H$ . As H increases beyond a certain point, the curve flattens out. That's *saturation*: the maximum flux density a given material can have.

## Faraday's Law

In 1831, Michael Faraday showed that moving a coil through a magnetic field (or moving a magnetic field through a coil) induces voltage in the coil:  $V = N(\Delta\Phi / \Delta t)$  where:

V is the induced voltage.

N is the number of turns of wire in the coil.

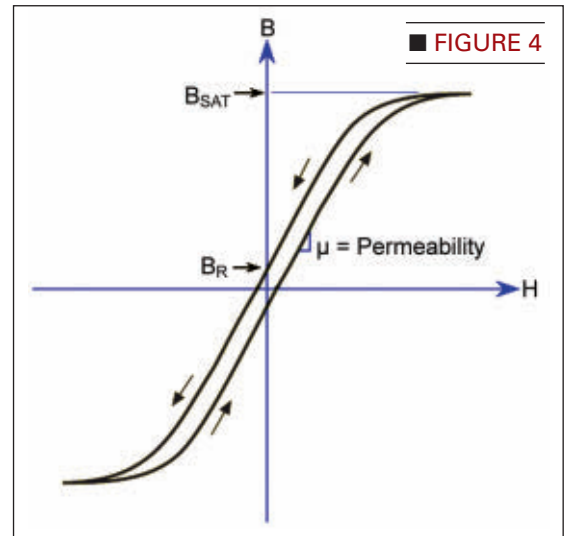
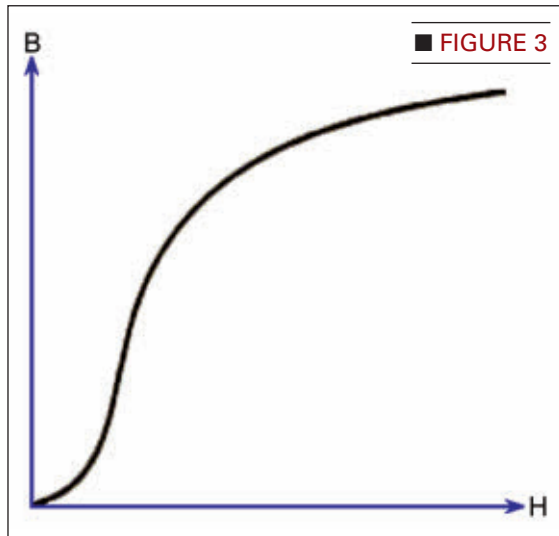
$\Delta\Phi$  is the amount of magnetic flux the coil "cuts."

t is the amount of time the coils cuts through the flux.

In Figure 2, closing the switch applies voltage across the coil. As coil current increases, mmf increases,  $\Phi$  increases, and a voltage is induced in the coil that is equal but opposite to the applied voltage. The induced voltage lasts until the core saturates. Then, the coil becomes a short-circuit across the battery. So, the maximum  $\Delta t$  in the above equation is the time it takes for the flux to go from zero to saturation ( $\Phi_{\text{sat}}$ ). Saturation causes current spikes so the maximum flux used ( $\Phi_m$ ) must be less than  $\Phi_{\text{sat}}$ .

## Hysteresis, Eddy Currents, and Power Loss

The B-H curve for magnetic



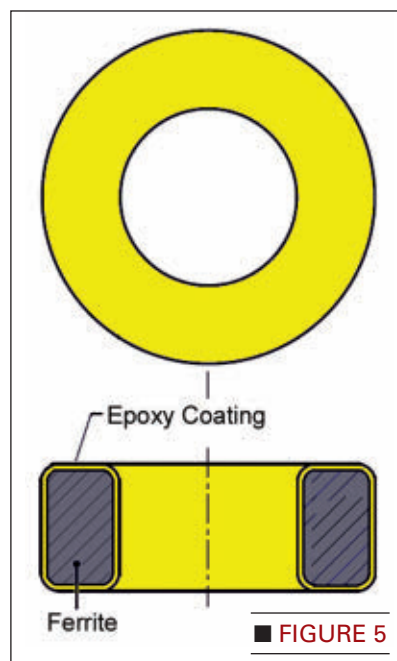
material is more complicated than Figure 3. Apply a magnetizing force to a bar of steel. When you remove the mmf, the bar is magnetized with *residual flux*. To demagnetize the bar, you have to apply reverse mmf. If the battery in Figure 2 is replaced by an AC source, you get the B-H curve of Figure 4: a *hysteresis loop*. Every time the core flux cycles around the loop, some electrical energy gets converted into heat. It's a form of *core loss*.

A changing magnetic field will induce voltage into any conductor it passes through, including the core itself. Voltage in the core causes *eddy currents* to flow producing  $I^2R$  core loss.  $I^2R$  in the coils is *copper loss*.

## Ferrite vs. Steel

Both hysteresis and eddy current losses increase rapidly with frequency. At audio frequencies, transformer cores are made from insulated steel laminations. Steel has very high permeability, but a lot of loss at switch-mode frequencies where *ferrite* is used instead.

Ferrite is a ceramic containing iron and other elements. It starts as clay-like material that can be formed into many shapes, then baked hard. It's brittle and can crack or break from too much mechanical stress. It has less permeability than steel, but much less loss at high frequency. Ferrite is conductive and abrasive, so often it's coated with insulation. Figure 5 shows a toroid core like the one we will use. A *toroid* is the ideal shape for a transformer core.



## Voltage and Flux

In Figure 6, the switches alternately

open and close producing square wave voltage on the primary. Starting at  $t = 0$ , flux increases according to  $\Phi = (V/N)t$ , producing triangle wave flux in the core as shown in Figure 7 (triangular as long as  $\mu$  doesn't change much with  $\Phi$ ). The current in the coil is also triangle wave.

Two points about Figure 7: First, flux goes from  $-\Phi_m$  to  $+\Phi_m$ , so  $\Phi = 2\Phi_m$ . Second,  $\Delta t$  is half the period, so  $\Delta t = T/2 = 1/2f$ .

## Turns per Volt

Rewrite Faraday's Law:

$$V = N(\Delta\Phi/\Delta t) = N(2\Phi_m)/(1/2f) = 4N\Phi_m f$$

Rearranging terms yields an important parameter: the *turns-per-volt* ( $N/V$ ).  $N/V = 1/(4\Phi_m f)$ . But  $\Phi_m = B_m \times A_e$ , where  $A_e$  is the effective cross section area of the core, so:

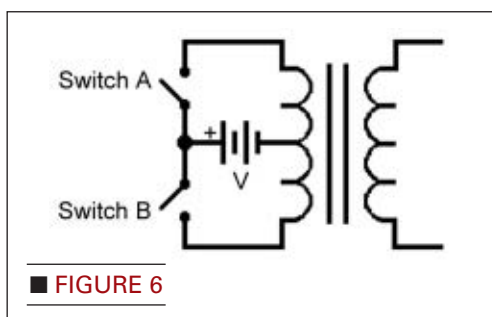
$$N/V = 1 / (4 B_m A_e f)$$

## Magnetizing Current ( $I_m$ )

The flux linking primary to secondary in a transformer is generated by the primary mmf which is  $90^\circ$  out of phase with primary voltage as seen in Figure 7. Since  $\Phi \propto I$ , primary current is also  $90^\circ$  out of phase with primary voltage so, except for losses, no power flows in. The primary looks like an inductor. The current in that inductor is the *magnetizing current*:

$$H_m = B_m/\mu \Rightarrow NI_m/le = B_m/\mu \Rightarrow I_m = (B_m le)/\mu N$$

where  $le$  is the effective length of the flux path. High  $I_m$



increases copper loss.

Putting a load on the secondary causes primary current to increase, but not flux in the core. The mmf caused by current in the secondary *cancels* mmf caused by the additional primary current, so there's no net change in flux.

## Terminology and Units

Table 1 shows the two sets of magnetic units.

Table 2 shows how to convert from one to the other. The unit for mmf is actually just amps. The number of turns is a dimensionless multiplier.

## Choosing a Core

We want a core that is efficient at 100 kHz with an internal diameter big enough so winding turns is easy. To minimize the number of turns,  $N/V$  should be between 1 and 2.

The core chosen for this project is a *FERROXCUBE* TX16/9.1/4.7 epoxy coated toroid. The part number gives the dimensions: 16 mm OD, 9 mm ID, 5 mm thickness. It's made from their 3C90 ferrite material, designed for power applications up to 200 kHz. From its datasheet,  $A_e = 14.7 \text{ mm}^2$  and  $le = 37.2 \text{ mm}$ . Core loss at 100 kHz and 100 mT is less than 55 mW. Similar cores from other manufacturers like *MAGNETICS* and *Fair-Rite* would work also.

$B_{max}$  for 3C90 is about 350 milli-Tesla (mT) at  $25^\circ\text{C}$ . Using  $B_{max}$  would lead to higher core loss and the danger of saturation. To be conservative, let  $B_m = 100 \text{ mT}$ . The turns per volt is:

$$\begin{aligned} N/V &= 1/(4 B_m A_e f) \\ &= 1/(4 \cdot 0.1 \cdot 14.7 \times 10^{-6} \cdot 1 \times 10^5) = 1.7 \end{aligned}$$

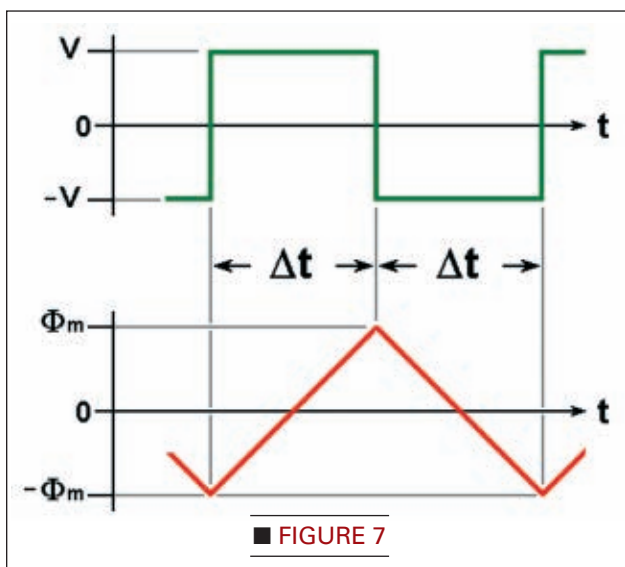


TABLE 1

PARAMETER	SYMBOL	UNITS	
		CGS	SI
Magneto-Motive-Force	<b>mmf</b>	Gilberts (Gb)	Amp-Turns (AT)
Magnetic Field Strength (Magnetizing Force)	<b>H</b>	Oersteds (Oe) (Gb/cm)	Amp-Turns/meter (AT/m)
Magnetic Flux	<b>Φ</b>	Maxwells (Mx)	Webers (Wb)
Flux Density (Magnetic Induction)	<b>B</b>	Gauss (G) (Mx/cm <sup>2</sup> )	Tesla (T) (Wb/m <sup>2</sup> )
Reluctance	<b>ℜ</b>	Gilberts/Maxwell	AT/Weber
Permeability	<b>μ</b>	Gauss/Oersted	Tesla/(AT/m)



## Calculate Np and Ns

Primary turns (Np) depend on primary voltage (Vp).  $N_p = V_p \times (N/V) = 9 \times 1.7 = 15.3$ , which rounds off to 15.

The 7812 and 7912 regulators need 2.5 volts between input and output. Adding 2.5 to 12 gives 14.5 volts. Adding 0.5 volts for the drop across the Schottky rectifiers gives 15 volts. Another 0.5 volts for loss gives  $V_s = 15.5$  volts.

Secondary turns  $N_s = (V_s/V_p) \times N_p = (15.5 / 9) \times 15 = 25.8$  which rounds up to 26. For a few less turns on the secondary, increase Bm a bit and recalculate N/V.

## Calculate Im

From the 3C90 specification sheet,  $\mu \approx 4 \times 10^{-3}$  at  $B = 100$  mT. So,

$$\begin{aligned} I_m &= (B_m l_e) / \mu N \\ &\approx (0.1 \bullet 37.2 \cdot 10^{-3}) / (4 \cdot 10^{-3} \bullet 15) \\ &\approx 0.062 \text{ amps} \end{aligned}$$

$I_m = 62$  mA is a reasonable value.

## Winding the Transformer

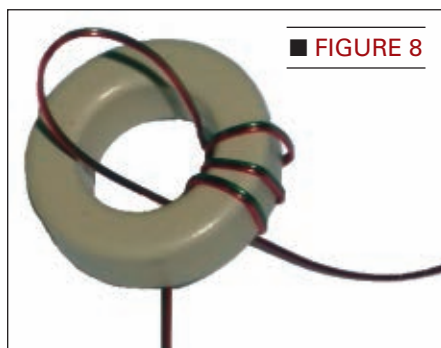
This is the fun part. You need:

- Toroid core (1)
- Bifilar wire, 28 Ga., 42 inches
- Nylon screw (1), 10-32 3/4 inch
- Nylon nuts (2), 10-32
- Fiber washers (2), center-hole for #10 screw [optional]

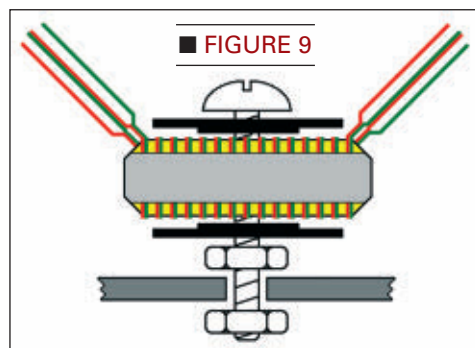
## Wind Primary and Secondary

We use *bifilar* wire: two strands of magnet wire glued together, with different insulation colors (e.g., red and green). It makes the center-tap very easy, but it's not available everywhere. Sources will be given in the Parts List.

You need 16 inches of wire for the primary and 26 inches for the secondary. Hold the core with the fingers of one hand. Put the primary wire through the core so that the short end forms a two inch lead; call it Lead 1. Use your thumb to hold the wire to the core.



■ FIGURE 8



■ FIGURE 9

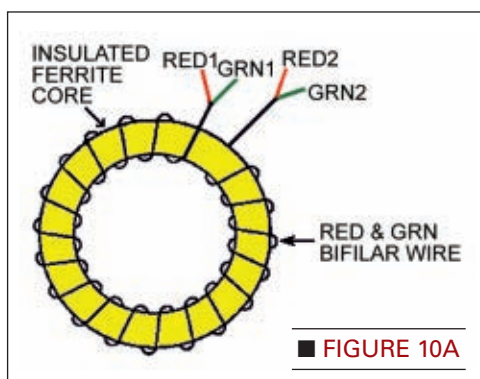
With your other hand, fold a small loop in the long end close to the core and push it through the center (Figure 8). Grab the loop and pull the wire all the way through. (A small stick helps. The cosmetic department of your local drug store may have a cuticle stick – the perfect tool!). Bend the wire around the side of the toroid and put your thumb on the new turn to keep it from unraveling.

Repeat the process counting the turns. Distribute the turns more or less evenly. Space the turns so the last turn ends up next to the first turn. Leads 1 and 2 form the last turn. For example, Figure 10A shows 19 turns. When you get to the end, cut the remaining wire to make Lead 2 the same length as Lead 1. Lock the leads with three twists close to the core (Figure 9).

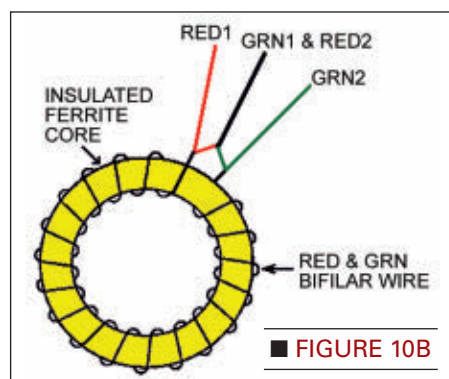
Lay four inches of plastic electrician's

■ TABLE 2

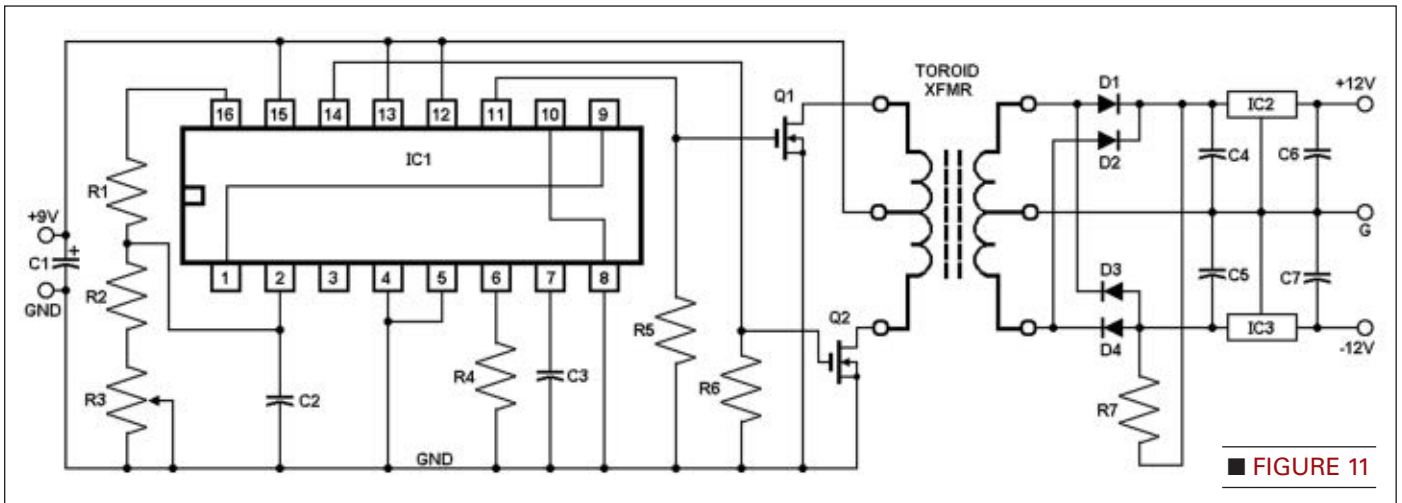
CGS	⇒	SI	⇒	CGS
Gilberts	$\times 0.796 =$	Amp-Turns	$\times 1.26 =$	Gilberts
Oersteds	$\times 79.6 =$	AT/meter	$\times 0.0126 =$	Oersteds
Maxwells	$\times 10^{-8} =$	Webers	$\times 10^8 =$	Maxwells
Gauss	$\times 10^{-4} =$	Tesla	$\times 10^4 =$	Gauss
Gauss	$\times 0.1 =$	milli-Tesla	$\times 10 =$	Gauss



■ FIGURE 10A



■ FIGURE 10B



■ FIGURE 11

tape on a cutting surface. Cut the tape lengthwise into strips about 1/4 inch wide. Take a strip and wrap it over the primary turns as shown in Figure 9. To tell the primary from the secondary later on, tie a small piece of thread around the primary leads. Start winding the secondary 180° opposite of the primary leads using the same procedure. When done, tape the secondary as you did the primary.

## Form the Center-Taps

Use a sharp tool to split the ends of the primary leads. Peel apart the red and green wires (Figure 10A). Take the red wire from one lead and the green wire from the other lead and twist them tightly together to form the center-tap (Figure 10B). Repeat on the secondary leads.

Scrape about 1/4 inch of insulation off the center-tap (CT) and the other wires of the primary. Tin the exposed copper ends. Repeat on the secondary wires. Use an ohmmeter to check continuity between CT and both wires of the primary; likewise for the secondary. Verify there is no continuity between primary and secondary.

## Add the Hardware

Refer to Figure 9. Insert the nylon screw

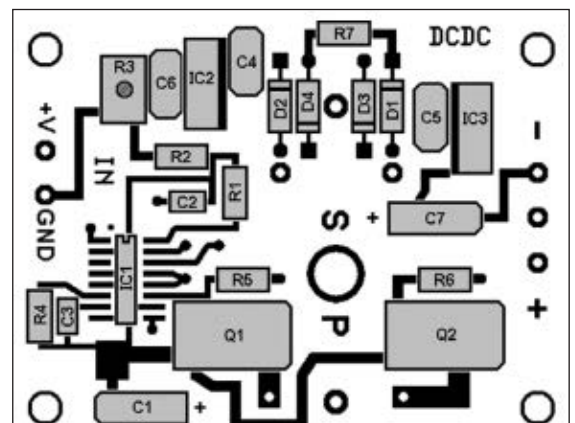
## PARTS LIST

All fixed resistors SMT size 1206, 5%

ITEM	DESCRIPTION
<input type="checkbox"/> R1, R2, R5, R6	1K
<input type="checkbox"/> R3	1K trimpot, 4 mm square, Cermet
<input type="checkbox"/> R4	5.1K
<input type="checkbox"/> R7	10K
<input type="checkbox"/> C1	10 $\mu$ F, 25V, 20% AVX Tantalum, SMT
<input type="checkbox"/> C2	0.1 $\mu$ F, SMT size 0805
<input type="checkbox"/> C3	0.001 $\mu$ F, SMT size 0805
<input type="checkbox"/> C4-C6	1 $\mu$ F, 50V, Ceramic, 0.2 inch radial
<input type="checkbox"/> C7	10 $\mu$ F, 25V, 20% AVX Tantalum, SMT
<input type="checkbox"/> IC1	LM3524DM/NOPB, SOIC-16
<input type="checkbox"/> IC2	7812
<input type="checkbox"/> IC3	7912
<input type="checkbox"/> Q1, Q2	MOSFET, SMT, IRFR024NTRPBF
<input type="checkbox"/> D1-D4	MBR150RLG (or equivalent)
<input type="checkbox"/> Terminal block	Two position, 0.2 inch spacing
<input type="checkbox"/> Terminal block	Three position, 0.2 inch spacing
<input type="checkbox"/> Core, ferrite	Ferroxcube TX16/9.1/4.7
<input type="checkbox"/> PC board	10-32 x 3/4 inch
<input type="checkbox"/> Screw, Nylon	Nylon, 10-32
<input type="checkbox"/> Nuts (2)	Fiber, Keystone #4702
<input type="checkbox"/> Washers (2)	42 inches, bifilar, 28 ga.
<input type="checkbox"/> Wire	

## SOURCES

- ☐ MWS Wire: [www.mwswire.com](http://www.mwswire.com)
- ☐ WireTronic: [www.wiretron.com](http://www.wiretron.com)



■ FIGURE 12



through a fiber washer. Insert the screw with the washer through the center of the toroid. Put the other washer on the screw and thread on a nut. Hand-tighten until snug. *DO NOT OVER TIGHTEN*. Figure 9 shows the transformer mounted on the circuit board using the second nut.

The transformer is done. Set it aside until needed.

## Circuit Description

Figure 11 is the schematic of the converter. IC1 (LM3524) drives power MOSFETs Q1 and Q2 which, in turn, drive the primary of the transformer in a square wave. Switching frequency is set by R4 and C3. The stepped-up voltage at the secondary is rectified and filtered to raw DC which is regulated down by IC2 and IC3. R7 prevents C4 and C5 from charging up to the peak of voltage spikes that can occur with an unloaded secondary.

R5 and R6 are pull-downs to speed up the turn-off of Q1 and Q2. Since the MOSFETs turn on faster than they turn off, both transistors would be on for a part of every cycle if they switched simultaneously, causing the transistors to get hot from current spikes. To prevent that, the LM3524 provides *dead time* between turning off one transistor and turning on the other. Dead time is set by the voltage at pin 2, adjusted by trim-pot R3.

## Construction

Figure 12 is the board layout. Components on the primary side are surface-mount (SMT) devices. (I'm using SMT since through hole parts are obsolete). The secondary side has mostly through-hole parts; I had a lot of the diodes and regulators, and wanted to use them.

There's an excellent video on soldering SMT devices on the *Nuts & Volts* Store page (<http://store.nutsvolts.com>) under the High Voltage Power Supply Circuit kit. I recommend viewing it before starting this project. Since the video is so thorough, I won't go into details about soldering here.

Mount IC1 — a 16 pin SOIC device — first. With a magnifier,

carefully inspect the solder joints. Then, mount C1, C2, C3, and C7. Check polarity on C1 and C7. Next, mount R1, R2, R4, R5, R6, R7, and trim-pot R3. Then mount Q1 and Q2.

Mount D1, D2, D3, and D4. Next, mount C4, C5, and C6. Then, mount IC2 and IC3. There are lines near the holes for IC2 and IC3 showing the positions of their metal tabs. Mount the two terminal blocks.

Before installing the transformer, connect the board to nine volts. Use an oscilloscope to look at the gates of Q1 and Q2. You should see a square pulse with a

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rep-rate of about 100 kHz. Adjust R3 and verify that the pulse width varies. If it's working properly, set R3 for minimum pulse-width and disconnect power. If it's not working right, disconnect power and examine the

solder joints on IC1. Verify that R4 and C3 are correct.

## Mount the Transformer

Refer to Figure 8. Mount the transformer with the primary winding facing the **P** on the circuit board. (Remember that piece of thread you put on the primary?) Install the second plastic nut and hand-tighten it to the board. Clip off excess screw length. Insert the primary leads with the center tap going in the center of the three holes and solder them. Similarly, insert the secondary leads in their three holes and solder. Insulation on some magnet wire allows you to solder through it. If your iron is hot enough and you hold it on the wire long enough, the insulation will dissolve. Otherwise, you need to scrape it off.

## Testing

Measure input current when you power up the board. If your supply has a current display, use it. If it doesn't, you can put a 1 $\Omega$  resistor in series with the supply and get the current by measuring the voltage across it. (I got tired of replacing fuses in my DMM when using its current range.)

Apply nine volts to the board. If current jumps past 0.25 amps, remove power and examine the board again. Double-check polarity on C1 and C7. Verify IC2 and IC3 are installed correctly. Look for solder bridges. If you can't find the problem by inspection, you can always re-apply the power and see what gets hot or starts to smoke. (I'm not kidding; I've had to do that on several occasions.)

If the board passes the smoke test, verify that you have +12V and -12V on the outputs with no load. Then put a 220 $\Omega$ , 1W resistor from each output to ground and verify that you still have +12V and -12V on the outputs. Use a voltmeter to measure the raw DC with and without a load. You'll see a drop with load. If the raw DC is too low with full load, you can increase it by adjusting R3.

## Wrap-Up

The LM3524 requires 8V minimum and has a 40V maximum supply limit. Use the board as a platform to test your own transformer designs. Try making one that uses 12 volts input. Try making a step-down transformer to get +5V and -5V outputs (replace IC2 and IC3 with a 7805 and a 7905). You can eliminate the regulators and install jumpers at IC2 and IC3 to bring the raw DC to the output terminals. Have fun with it! **NV**



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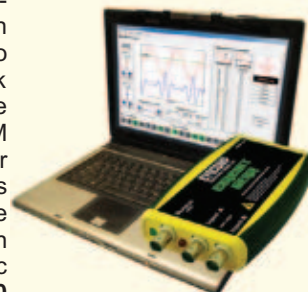
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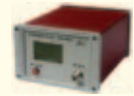
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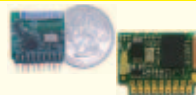
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# MAKING THE DEFCON 16 BADGE

by Joe Grand



Every summer, thousands of hackers and computer security enthusiasts descend into Las Vegas for DEFCON ([www.defcon.org](http://www.defcon.org)) — the largest and oldest continuously running event of its kind. It's a mix of good guys, bad guys, government officials, and everyone in between, all focused on having fun, sharing technical information, seeing old friends, and learning new things. This is the third year in a row that I've had the honor of designing the conference badge for DEFCON. Unlike other conferences where boring plastic or metal badges are used, DEFCON has been setting the trend since 2006 in giving out full-featured, active electronic badges to their attendees and challenging them to do something unique with their new-found technology.

This article highlights my design process and the problems that I encountered during the creation of the DEFCON 16 Badge. Hopefully, you'll be able to learn from my mistakes or build on my work to enhance your own endeavors.

## A Brief History of the DEFCON Badge

The previous years' electronic badge designs each had their own set of unique challenges, interesting lessons, and frustrating problems. The DEFCON 14 badge was a round PCB with complicated cutouts of graphical elements and consisted of a six pin Microchip PIC10F202, two jumbo blue LEDs, and a single CR2032 Lithium coin cell. The badge had four different LED modes (on, blinking, alternating, random) and a Microchip ICD2 programming interface for attendees to load their own customized firmware onto the badge. We didn't know what to expect when we started handing them out to conference attendees, but the response was overwhelming, which led to a new badge design for the next year.

I upped the ante and the technical complexity of the DEFCON 15 badge by using a Freescale MC9S08QG8, a 95 LED matrix (five columns by 19 rows) for custom scrolling text messages, capacitive touch sensors, and unpopulated areas for accelerometer and 802.15.4 wireless support. You can read all about the trials and tribulations of the DEFCON 15 badge in the July 2008 issue of

*Nuts & Volts*. Even with the success of the badge, I felt that I had over-engineered it and that it contained too much for attendees to digest over the weekend. So with DEFCON 16, we wanted to have an electronic badge that could still be personalized in some way, but without a lot of "noise" to detract people from the key features and turn them off from hacking their badge.

## Design Goals

The primary goal of the DEFCON 16 badge was to incorporate a file transfer feature to allow an attendee to transfer files to another attendee using his or her badge, not unlike the "beaming" capability of PDAs and smartphones. Attendees would load their desired file — be it a business card, picture, poem, or write-up of their latest discovery or research — onto a SecureDigital (SD) card, insert it into the badge, and transfer it to a willing recipient via infrared. Just like last year's badge in which attendees could display a customized text message onto it, the file transfer functionality of DEFCON 16 would meet this same "personalization" goal, allowing attendees to make their badge unique based on what sort of information they chose to share with others.

With over 8,500 attendees expected at the conference, I assumed that only a small percentage would actually take advantage of the file transfer capabilities, even though that was to be the core functionality of the badge. I wanted the

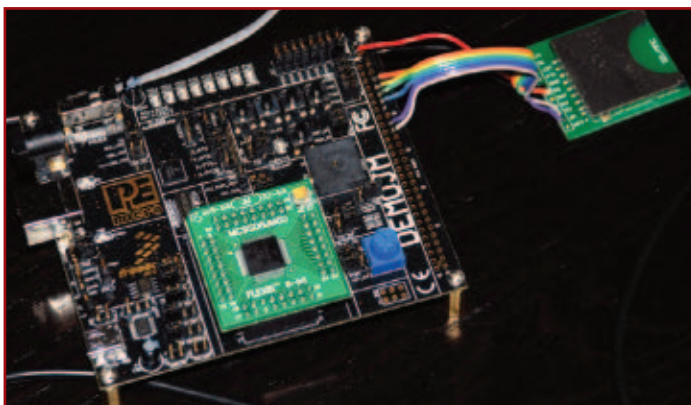


badge to do something interesting right out of the box if the user didn't insert an SD card into the socket. I decided to incorporate "TV-B-Gone" functionality into the badge and take advantage of the infrared components that would already be in place. The original TV-B-Gone ([www.tv-b-gone.com](http://www.tv-b-gone.com)) product was designed by Mitch Altman of Cornfield Electronics. The unit simply transmits all known television remote control power-off codes one after another, allowing you to turn off practically any TV in North America, Asia, or Europe. Depending on how the TV-B-Gone is used, it can be quite mischievous and I thought it would be suitable for a hacker conference where people are used to taking advantage of and pushing the bounds of technology. Above and beyond the engineering design goals, there were some fundamental requirements:

- **Aesthetics.** The badge needed to look nice and be as non-intrusive to the wearer as possible. From the graphics to the routing to the parts placement to the circuit board traces, every aspect of the badge design was considered.
- **Low Cost.** The badges had to be cost-effective. The goal was a \$7 total BOM (bill of materials) cost per unit including components, programming, PCB manufacturing, assembly, and testing for 8,500 pieces. Meeting the badge budget has been a major challenge in previous years.
- **Hackable.** The badge should be completely "hackable" in nature by providing source code, schematics, and development resources for those who wanted to modify their badge to do something different and out of the ordinary. Although any product can be hacked without provisions to do so, I wanted to make the badge welcoming to hackers and foster the hacking spirit so prevalent at DEFCON.
- **Continued Use.** The badge should be designed to provide a general-purpose development environment or reference platform that attendees can build on and learn from after the conference.

## Engineering Process

With the design goals in mind, I first put together a system-level block diagram — basically a high-level conceptual drawing to help me visualize the overall design. The design is based on a Freescale Flexis MC9S08JM60 eight bit microcontroller ([www.freescale.com/webapp/sps/site/prod\\_summary.jsp?code=S08JM](http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=S08JM)) and has interfaces to the SD card socket, infrared transmission and receiver circuitry, USB port, and debug/programming connector. The JM60 microcontroller has 60KB of Flash, 4KB of RAM, a 12 channel, 12 bit ADC, USB 2.0 full-speed device support, two SPI (Serial Peripheral Interface) modules, two SCI (Serial Communications Interface)/UARTs, two timer/PWM modules, eight keyboard interrupts, real-time clock, internal reference clock, and 51 general-purpose I/Os. It's a powerful part and has lots of on-chip functionality that I could take advantage of. A set of eight LEDs on the front of the badge is used as status and mode indicators. I had over 68,000 LEDs leftover from last year's DEFCON 15



■ FIGURE 1. Freescale's DEMOJM evaluation board with an added SD card socket used for my initial development.

badge and wanted to do something with them.

The next step was to start developing with actual hardware. I used Freescale's off-the-shelf DEMOJM evaluation board (Figure 1; [www.freescale.com/webapp/sps/site/prod\\_summary.jsp?code=DEMOJM](http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=DEMOJM)) and CodeWarrior Development Studio for Microcontrollers — which is freely available for up to 32KB of code ([www.freescale.com/webapp/sps/site/prod\\_summary.jsp?code=CW-MICROCONTROLLERS](http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=CW-MICROCONTROLLERS)) — to get the basic firmware and state machine environment set up. Then, I added an SD card socket to the DEMOJM's expansion header and continued with the firmware development until I was comfortable that the intended functionality of the badge would succeed.

After that, using the block diagram as a rough guide, I built a custom circuit board with only the specific hardware that I wanted to have on the badge. I also designed in provisions for a few elements that I hadn't yet completely decided on, like how to support the infrared transmission and reception (discrete components or an IrDA-compliant module) and battery selection (AAA or something else). The hardware and firmware designs were finalized on this board before moving to the next step, which was a true-to-form pre-production prototype. Using an intermediary board like this allowed me to not only verify my schematic, but also to easily make changes to component values and take measurements of various signals to aid in troubleshooting and diagnostics. The majority of hardware and firmware development was done on this platform before moving to the "form and function" pre-production prototype.

With the hardware and firmware completed, the final task was to lay out the actual badge circuit board and build a few pre-production prototypes to verify the entire system before kicking off the production run. I ordered a few bare boards with yellow soldermask and red silkscreen, hand-soldered them, and ran through my test procedure to verify that the individual aspects of the badge worked as desired. This step was the last chance for me to correct any mistakes before committing to many thousands of dollars of circuit boards and components. I also used these prototypes as samples for DEFCON to approve.

Using two hand-soldered pre-production prototypes let

me verify that the complete design looked and worked as desired. Each board took about one hour to assemble.

The total BOM cost per unit was \$10.72, not including taxes or shipping. The largest line items were the PCB fabrication, manufacturing, assembly, and testing at \$3.88 and the microprocessor at \$1.95. What I thought would be the hardest part of the project (the engineering) was completed with relatively few mishaps.

## Badge Functionality

The DEFCON 16 badge packed in lots of functionality using minimal components. A single pushbutton switch serves as the user interface to cycle through the badge's three operating states: Receive file; Transmit file (or TV-B-Gone if no SD card is inserted); and Sleep. Let's take a look at the technical details of the major subsystems of the badge.

## Infrared Remote Control and TV-B-Gone

For the infrared (IR) subsystem, I decided on using on-off keying — one of the oldest and simplest modulation techniques. I would essentially turn on and off a low frequency carrier (in our case, 38 kHz) in order to modulate data. Then, using an encoding scheme known as Pulse-Width Encoding, I defined a logic 0 and logic 1 by the width of the "on" pulse, while the pulse distance (the distance in between the pulses) or "off" pulse remained constant. This no-frills approach is used by just about every infrared remote control device on the market and the only circuitry I needed was an infrared LED (D9), current-limiting resistor (R9), and transistor driver (Q1, R11, R13).

I opted for this discrete approach over using an IrDA ([http://en.wikipedia.org/wiki/Infrared\\_Data\\_Association](http://en.wikipedia.org/wiki/Infrared_Data_Association)) transceiver module — a common, robust solution for file transfer between computers or consumer devices — for a number of reasons. Many IrDA modules (such as the Vishay TFDU4300) require an additional encoder/decoder (whether done in hardware, like the Vishay TOIM4232, or software) to convert serial data to IrDA-compatible pulses. I also felt that a discrete solution would be more hackable, as one could modify the firmware to generate any sort of IR transmission desired, instead of being forced to adhere to the imposed standards of the IrDA module. Cost was a concern, as well, and I was able to implement the discrete IR circuit for \$1.48 versus approximately \$6 I would have had to pay for a fully IrDA-compliant design.

I used one of the JM60's timer/PWM channels to generate a 38 kHz carrier at a 33% duty cycle and could turn the carrier on or off by simply enabling or disabling the PWM channel. As an initial infrared test, I decided to impersonate a Sony TV power off code to see if I could turn off my television using my badge development board. The Sony remote control specification is well documented online and defines a logic 1 as a 0.6 ms off pulse followed by a 1.2 ms on pulse, and a logic 0 as a 0.6 ms off pulse

followed a 0.6 ms on pulse. I simply duplicated the entire pulse train for a power-off signal, not caring about what data I was actually transmitting. The test worked perfectly! Now, I could move on to incorporating the TV-B-Gone functionality. I captured this signal from an IR remote control receiver module, so it is inverted.

The TV-B-Gone simply transmits all known television remote control power-off codes at their pre-defined carrier frequency and pulse-width timings, one after another. The open-source version of the TV-B-Gone ([www.ladyada.net/make/tvbgone](http://www.ladyada.net/make/tvbgone)) contains a header file with all of that information. I grabbed the header file and ported the TV-B-Gone functionality to the badge by parsing the data, properly configuring the PWM channel, and turning the carrier on and off at the correct timing. The IR LED (Osram SFH4650-Z, D9) that I selected for the badge is low power and narrow beamwidth ( $\pm 20$  degrees half angle). The narrow beamwidth is especially important for the file transfer mode to prevent interference between multiple people transferring files within the same area. Because of that, the TV-B-Gone functionality only works with televisions a few feet away. Most attendees who really wanted to take full advantage of the TV-B-Gone mode replaced the stock IR LED with a high brightness, wide beamwidth LED to get the farthest range possible.

## Infrared File Transfer with SecureDigital Card and FAT File System Support

As opposed to the transmit-only functionality of the TV-B-Gone mode, a file transfer requires one badge to transmit and one badge to receive. The badge uses a Sharp GP1US301XP infrared receiver module for remote controls, which is tuned to 38 kHz (the same as my IR transmit modulation frequency). The receiver will bandpass the incoming signal to help reduce noise caused by the ambient environment (in particular, lighting) and then provide a demodulated signal at logic levels that can easily be interfaced with a microprocessor. The goal of the file transfer feature is to read a file from an SD card, transmit it to a willing recipient, and store the received file onto the recipient's SD card. The physical interface from the SD card socket to the JM60 microprocessor is as simple as it gets. In its most basic configuration, SecureDigital uses an SPI interface, consisting of four lines — Master In Slave Out (MISO), Master Out Slave in (MOSI), Clock (CLK), and Chip Select (CS) — for its MultiMediaCard (MMC) protocol. Two additional switches on the socket — Card Detect (CD) and Write Protect (WP) — are connected to two general-purpose inputs on the processor. It is trivial to read and write data to the SD card using SPI, as it's essentially just an external serial memory device, but the trick is incorporating the FAT file system structure ([http://en.wikipedia.org/wiki/File\\_Allocation\\_Table](http://en.wikipedia.org/wiki/File_Allocation_Table)) so you can load and retrieve files from any computer system.

There are lots of available implementations of FAT for embedded systems and it didn't make sense for me to try



and recreate the file system from scratch. As luck would have it, Freescale was in the midst of creating a small reference design — a data logger with light sensor, USB, SD card, and FAT file system. It wasn't publicly released, but they were gracious enough to share their source code with me, which gave me a huge head start on getting my implementation working. Freescale's design only supports SD cards that have been formatted in FAT16, which means it will only work with cards 64 MB or larger. Windows automatically formats cards less than 64 MB as FAT12, which will lead to a corrupted FAT table on the SD card if used in the badge. I learned this the hard way after countless hours of troubleshooting.

With the low-level SD card and FAT file system support complete, I could move on to designing the actual file transfer mechanism. Instead of making use of an existing file transfer protocol like Kermit or XMODEM, I decided to roll my own version, which would be more educational (though much less graceful). I decided to build on the same on-off keying and pulse-width encoding schemes that were used for my initial infrared transfer tests with the Sony protocol, and added a mechanism to send large streams of data instead of short remote control codes. I reduced the pulse width timing in order to increase data transmission speed and added a way to send the filename, file size, and CRC along with the actual file.

## USB Debug Console and Bootloader

In previous years' designs, the only way a badge user could load new firmware onto the badge was through whatever proprietary programming/debugging interface was provided by the selected microprocessor. DEFCON 14 used the Microchip PIC ICD2 interface and DEFCON 15 used Freescale's BDM (Background Debug Mode) interface, and both required specialized hardware. I think that hindered participation in previous Badge Hacking Contests, as I only brought a few programming units to share.

The USB interface on the DEFCON 16 badge serves two distinct purposes. Most important is the bootloader functionality, described in Freescale's application note AN3561 ([www.freescale.com/files/microcontrollers/doc/app\\_note/AN3561.pdf](http://www.freescale.com/files/microcontrollers/doc/app_note/AN3561.pdf)), that allows in-circuit reprogramming of the JM60's Flash memory. With the bootloader enabled (achieved by holding down the mode select button while applying power to the badge), the user simply needs to connect their badge to a PC with the mini-USB connector and load their compiled code onto the badge using a free GUI. The only downside is that no debugging capability exists through the bootloader. If, for some reason, the firmware gets corrupted through a faulty programming operation, a standard six-pin BDM header is also made available on the badge for complete re-programming.

The USB bootloader satisfied our requirement of a hackable badge. Since no specialized development hardware was necessary to modify the firmware of the badge, the pool of potential badge hackers increased tremendously.

When not being used by the bootloader, the USB port serves as a virtual serial port created using the standard USB Communications Device Class (CDC). With the proper driver installed (which was included on the DEFCON CD), you can simply load up your favorite terminal program, and transmit and receive serial data. I used this feature during development to send debug messages and left the capability enabled for attendees to explore and use.

## Power/Batteries

The selection of power supply components and batteries was a key challenge of this design. I did not want to repeat the problems of last year's badge, in which the batteries would be depleted within two days if the badge was heavily used. There were five elements I needed to be concerned with, in order of priority: Battery Life (must last longer than the weekend-long DEFCON); Availability; Cost; Complexity; and Weight. I began by taking current measurements of the major operational states of the badge on my custom development board (all @ 3V):

- Sleep = 0.79 mA
- IR Receive mode = 5.3 mA
- IR Transmit mode (continuous data transmission) = 9.1 mA
- SD Card (continuous read and write) = 25-35 mA, but can be as high as 200 mA, according to SecureDigital specification

When the USB connection is plugged in, the badge automatically increases the microcontroller's clock speed from 12 MHz to 48 MHz (required for the JM60's USB module to function), so current consumption increases across the board by about 20 mA.

My previous DEFCON badges used one or two 3V CR2032 Lithium coin cells, which are lightweight and low profile. However, they aren't suitable for high-current applications (greater than 3 mA continuous or 10 mA pulse), so they couldn't be used for this year's design. The original plan was to try and power the badge from a single AAA battery. After looking into some single-cell boost converters/regulators— such as the Micrel MIC2571, Sipex SP6644, and Sipex SP6641B — to boost the 1.5V nominal battery cell voltage to a higher system voltage, I decided that, although suitable for many consumer electronic devices, the additional external components (such as inductors and specialized capacitors), critical PCB layout, and potential switching noise introduced into the system, would have made this direction too risky to use on the badge with such a short development cycle.

Next, I had narrowed down the selection to either three AAA batteries or a single CR123A Lithium cell. Both were easily available at convenience, photography, and electronics stores, though the AAAs are arguably more common and definitely cheaper. It was now apparent that whatever battery solution we went with would be heavier

and more bulky than we would have liked, but my primary concern was making sure the system would function as designed, and I'd just brace for any negative comments (of which there were very few). I spent hours on the phone with the DEFCON organizers discussing battery chemistry and the pros and cons of each battery type. They chose to move forward with three AAA batteries, which would provide 4.5V at 1,250 mAh that I could bring down to a 3V system voltage with a low-cost linear regulator. But, when I started to look around to purchase 25,500 surface-mount AAA battery holders, there was not enough stock world-wide and the manufacturer's leadtime was past the date of DEFCON, which killed this approach on the spot.

We settled on using the CR123A, which I now know is a better, simpler solution. The battery has built-in PTC (Positive Temperature Coefficient) protection to limit current flow in a short circuit or battery failure condition, and doesn't require any external voltage regulation circuitry in order to be used in our system (thanks to the stiff voltage output the battery has until it's close to end-of-life). The above current measurements show that with a single 3V CR123A rated at 1,400 mAh, the badge can last for hundreds of hours of normal use, satisfying our requirement that the badge remains operational for the length of DEFCON.

## Circuit Board

Creating the badge electronics was only one part of the battle, as aesthetics of the badge was also a fundamental design goal. Each year when the folks at DEFCON say "Let's try to make a badge that looks like this," they're saying it purely from an artistic point of view. They're not concerned with any electrical characteristics, manufacturing methods, or PCB related limitations or constraints. That naivety is

what pushes me to try PCB design and layout techniques that I wouldn't normally consider in order to meet their proposal. There were a number of major elements to the badge's circuit board design: the physical board outline's subtle curves; the complicated text cut-outs for the conference attendee type; masking certain areas of solder-mask to bring out graphics on the copper layer; and parts placement, such as the arc of LEDs along the bottom edge and locating the IR transmitter in the ninja's left eye. I made a conscious decision to leave all parts designators off of the badge. This lends itself to a much cleaner look at the expense of easy parts identification. The assembly drawings were available to people curious about hacking or modifying the badge to make their job easier.

I had added in a few surprise graphical elements, such as a two-dimensional Data Matrix barcode (<http://en.wikipedia.org/wiki/Datamatrix>) and a secret message used for the Mystery Challenge — a popular hardware hacking/puzzle contest at DEFCON.

## Until Next Year ...


All told, the DEFCON 16 badge project took about 220 hours, including the firefighting of supply chain and manufacturing problems after development was completed. The majority of engineering was done on nights and weekends, much to the chagrin of my very pregnant wife, Keely, as I was then spending my days as a co-host of Prototype This ([www.discovery.com/prototypethis](http://www.discovery.com/prototypethis)). Thankfully, most of my time was spent doing what I love to do — engineering.

We've already started to think about designs and features for the DEFCON 17 badge and have had a lot of great input from attendees and badge hacking contest

participants. Next year's design will be even simpler and more accessible to electronics hobbyists and beginner hardware hackers, but will also contain some "so new it doesn't even exist yet" technology to impress even the most hardened gadget geek. Even though I'll be keeping the lessons of previous years' badges in the back of my mind, I can all but guarantee there will be unexpected problems this time around. Who ever said engineering was boring?!

Complete source code, schematics, audio, video, and other documentation for the DEFCON 16 badge is available at [www.grandideastudio.com/portfolio/defcon-16-badge](http://www.grandideastudio.com/portfolio/defcon-16-badge) **NV**


*Due to space limitations, the article presented here is a condensed version of the original. To read the complete article, go to [www.nutsvolts.com](http://www.nutsvolts.com).*



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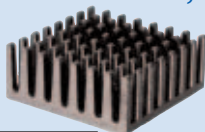
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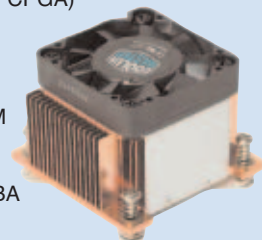
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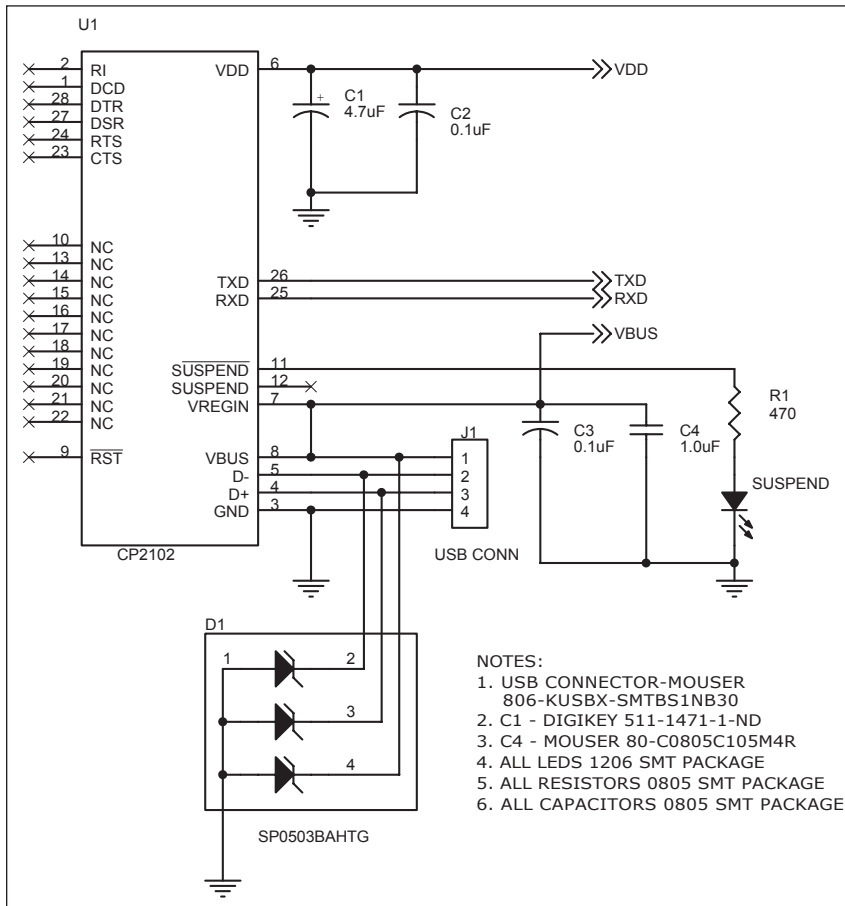
# DEMYSTIFYING USB TO SERIAL

IN THE PREVIOUS INSTALLMENT OF DESIGN CYCLE, we went to school and studied the Silicon Laboratories CP2103 USB-UART bridge. If you had the opportunity to take a look at last month's Design Cycle, you have enough CP2103 theory under your belt to build up your own USB interface. However, as Gomer Pyle would say, "Surprise! Surprise! Surprise!" If you took the time to be part of our previous discussion, you also have what it takes technically to put a CP2102 to work in your projects, as well.

It's time to stop talking and start soldering. This month, you have your choice of USB projects. One project shows you how to fabricate a microcontroller utility board based on a PIC18LF4620 that is front-ended with a CP2103. The alternate project includes an identical

microcontroller layout but substitutes a CP2102 for the CP2103. Let's talk about why you may want to choose the CP2102 over the CP2103 for your USB interface.

## CP2102 OR CP2103



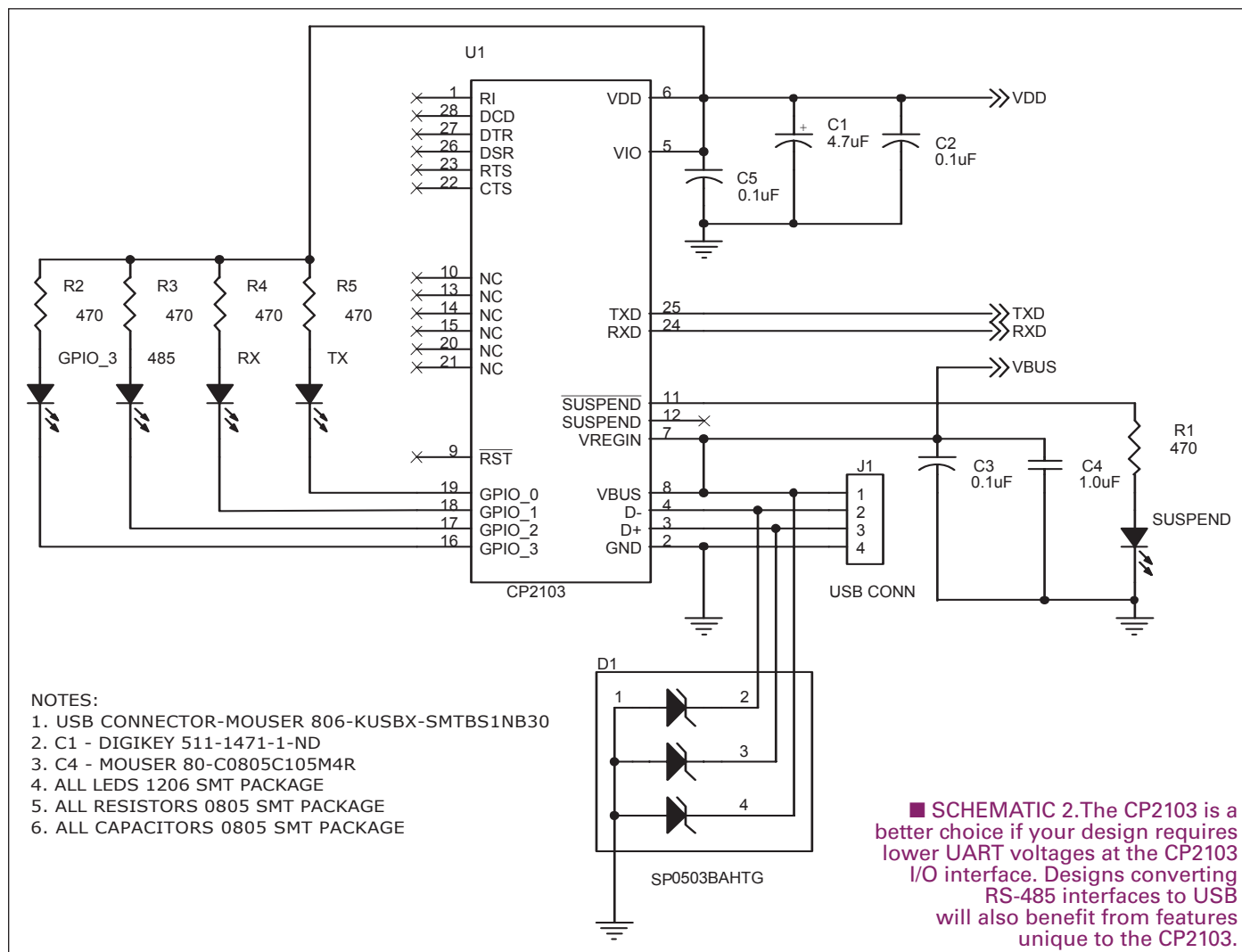
Both chips are upgraded versions of the CP2101. And compared to its younger brothers, the CP2101 is vastly less capable in the UART area and is no longer recommended for new designs. If you happen to have some CP2101 parts floating around (*who doesn't? -Ed.*), you can plug them into our CP2102 project without having to perform any printed circuit board modifications. Two project PCBs are necessary as the CP2103 is not pin-compatible with the CP2102.

The CP2102 and CP2103 transceivers, clocks, and EEPROMs are integrated into the silicon and eliminate the need for any additional external ICs, crystals, or resistors. The internal power subsystems of the transceivers are also identical in physics and operation.

Our CP2102 design is depicted graphically in Schematic 1. If you compare Schematic 1 with the CP2103 design you see in Schematic 2, you'll notice that the

■ **SCHEMATIC 1.** If we wanted to take this design down to the bare minimum, we could get away with just the CP2102 and the four capacitors. However, I didn't find an example design in the CP2102 factory data that was without the optional transient voltage suppression (TVS) diodes.





CP2102 does not include a VIO pin. The CP2103 uses the voltage applied to its VIO pin as a reference for the voltage levels applied at its I/O interface. Voltage levels at the CP2103's I/O pins can range from 1.8 volts to VDD (3.3 volts). The CP2103 also supports open drain connections to certain I/O pins. Pins configured like this can interface with I/O voltage levels between VDD and +5 volts using pull up resistors. As you can see in Schematic 2, we have limited our I/O interface voltages to the VDD level by tying the VIO input directly to the CP2103's 3.3 volt VDD output.

Another look at Schematic 2 tells us that the CP2103 has four I/O lines that don't exist on the CP2102. The quad of CP2103 GPIO\_x signals are controlled by Silicon Laboratories-supplied API calls issued over the USB interface. The GPIO\_x pins can also be programmed to take on predetermined or device-controlled tasks. When the GPIO\_x I/O interface is under the control of the CP2103 hardware, the GPIO\_0 and GPIO\_1 pins become transmit and receive indicators respectively for converted RS-232 and RS-485 links. When the CP2103 is used in an RS-485 environment, GPIO\_2 serves as the RS-485 transmit/receive interface control pin.

The final CP2102/CP2103 differentiator is the CP2103's Dynamic Suspend feature. By default, the latch values of the CP2102 and CP2103 I/O interfaces remain static during the USB suspend state. The Dynamic Suspend feature allows the programmer to set the CP2103 interface pin latch to a predetermined state when the device moves from the USB configured state to the USB suspend state. The previous value of the interface pin latch is restored when the device exits USB suspend state.

So, here's the bottom line. If you need a UART interface with extended voltage level flexibility or if you need to convert an existing RS-485 interface, the CP2103 is a better choice. Otherwise, the CP2102 is sufficient to supplant a standard RS-232 interface in most applications.

## INSTANT GRATIFICATION

The USB interface circuits we are about to build up are really challenging and exciting. However, just blinking the LEDs attached to the CP2103's GPIO pins is not our goal. The idea is to put the new embedded USB interfaces to work as replacements for legacy embedded RS-232 interfaces.

Schematic 3 represents a simple PIC implementation that is supported by a CP2103. The Microchip hardware behind the CP2102 is shown in Schematic 4. I have chosen to use the PIC18LF4620 as it supports multiple timers, numerous communications protocols, and lots of I/O. The *LF* in the PIC part number tells us that the PIC18LF4620 can also operate efficiently with a 3.3 volt power rail. Just in case you need to run your PIC and peripherals at 5.0 volts, I've designed in a jumper to allow you to use VBUS (+5 volts) or VDD (3.3 volts) to power the PIC. Both the CP2102 and the CP2103 I/O and UART are five volt tolerant.

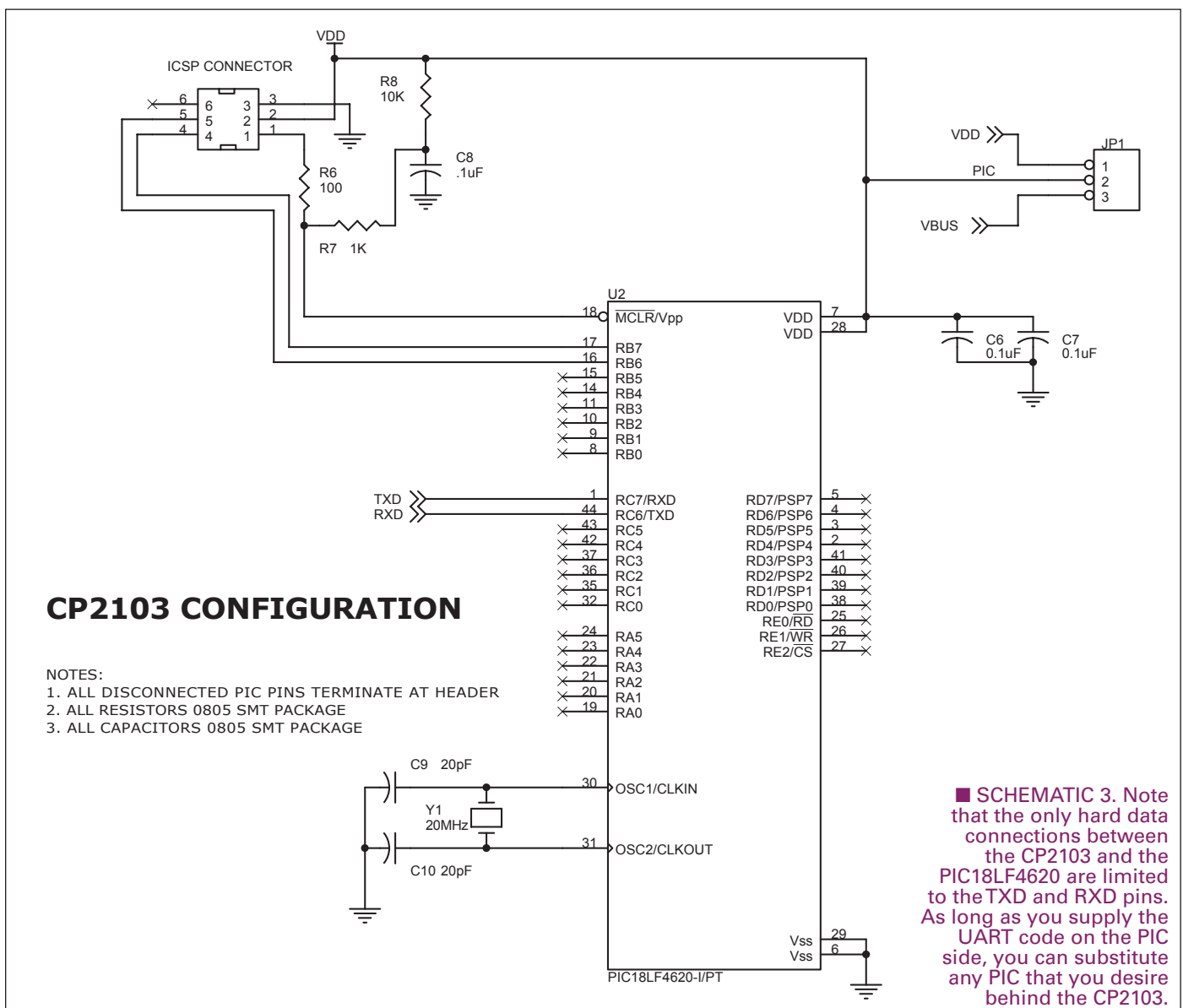
## ASSEMBLING THE UNITS

You can only purchase a CP210x IC in the QFN-28 package. So, in keeping with the intent of the QFN package, at every opportunity we'll design in SMT components. I realize that many of you have access to

SMT soldering and rework equipment. I also realize that most of you probably don't. I want to be sure that any *Nuts & Volts* readers with reasonable soldering skills can assemble these projects. So, to prove that manual SMT soldering can be used, I'll assemble both projects using common sense, SMT soldering techniques that you can easily understand and apply.

The solder sides of a CP2102 and CP2103 are under the lens in Photo 1. If we can get the CP210x on straight, the rest of the assembly process will be a walk in the park. Normally, I would use a stencil to lay down the solder mask for a part like this. Following a highly magnified precision mounting process, I would run the fully stuffed PCB through a batch oven. However, in that you may not have a batch oven and a precision rework station, we'll mount the CP210x parts the cheap-and-not-as-easy way.

There are many ways we can manually mount and solder the CP2102 and CP2103. No matter which project variant you decide to build up, to make the job easier



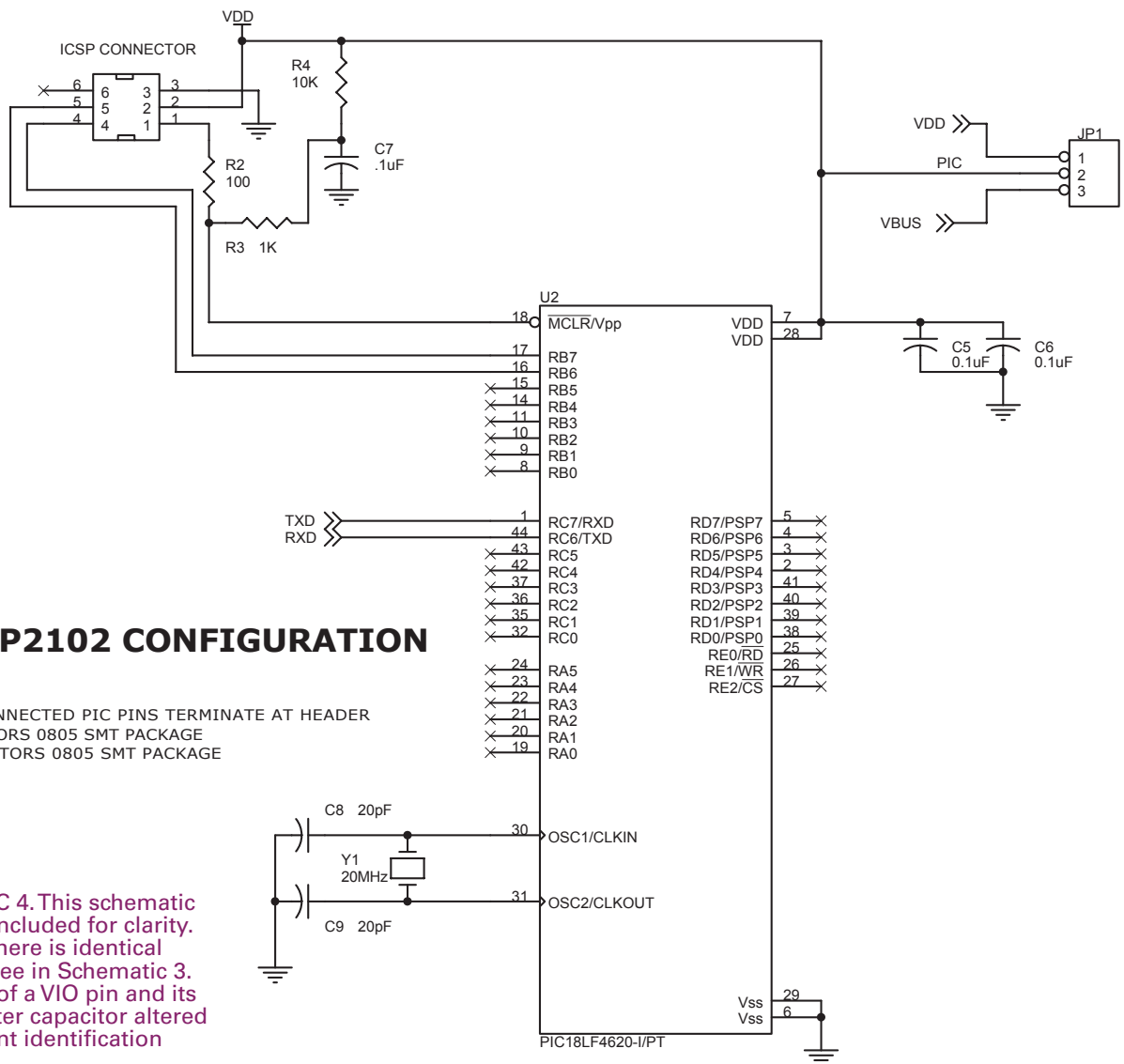


## CP2102 CONFIGURATION

### NOTES:

1. ALL DISCONNECTED PIC PINS TERMINATE AT HEADER
2. ALL RESISTORS 0805 SMT PACKAGE
3. ALL CAPACITORS 0805 SMT PACKAGE

■ **SCHEMATIC 4.** This schematic rendering is included for clarity. The circuitry here is identical to what you see in Schematic 3. The absence of a VIO pin and its associated filter capacitor altered the component identification scheme.



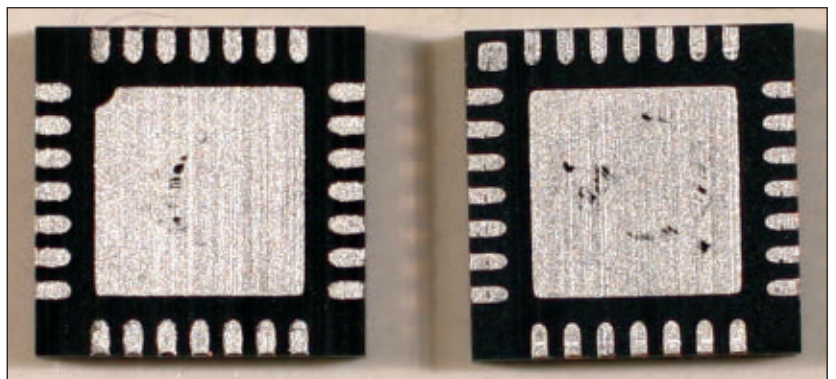
you'll need a magnifier, some solder paste, and a fine pitch soldering tip. The difficulty of successfully soldering in the CP210x can be reduced if you have access to a hot air soldering system. A hot air soldering station also comes in handy when it comes time to remove a fine-pitched SMT component like the CP210x.

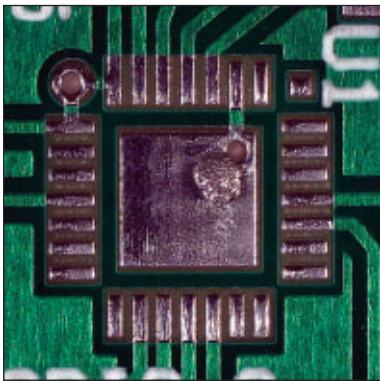
Begin the soldering process by applying a small dot of solder on the CP210x's ground pad via as shown in Photo 2. The ground pad via is supplying a ground connection to the PCB pad by way of the ground plane on the solder side of the PCB. The idea is to electrically connect

(solder) the CP210x's ground pad to the solder plating of the PCB land pattern by heating the solder-laden via.

The next step involves carefully lining up the CP210x pins to their respective pads. Pay careful attention to the orientation of pin 1 of the CP210x, as the pin 1 position is closest to the *U1* silkscreen designator. A small square marks the pin 1 corner of the CP2103. Although the

■ **PHOTO 1.** The large area in the center of the parts is a grounding pad. Letting the grounding pad float electrically is not an option. To keep the components as compact as possible, I used a via in the printed circuit board ground plane instead of a trace to the CP210x's ground pin. Note the pin 1 square marker on the CP2103 on the right versus the semicircle cutout on the CP2102 to the left.





■ PHOTO 2. What we want to accomplish here is lay down just enough solder to allow us to bond the CP210x's ground pad to the printed circuit board pad by heating the via. We also don't want to spill any solder paste over into the pin area. Note the tiny dab of solder paste in the upper right corner of the ground pad.

orientation for the CP2102 and CP2103 places the package pin 1 designator dot in the position shown in Photo 3.

Once you're sure about the CP210x's orientation, tack down the part by soldering a couple of its opposing corner pads. After you have secured it in position, heat the ground pad via from the solder side just enough to flow the solder paste you placed on the ground pad via. If things go as planned, you will bond the solder plating inside and around the ground pad via to the CP210x ground pad. If you use an ExpressPCB PCB, the extra solder plating on the pads will also reflow and provide some additional solder for the joint. Once the CP210x is solidly in place, you can carefully solder the rest of its perimeter pads. If possible, use solder paste exclusively as you can easily place a small dot of solder where you want it with a toothpick or similar pointed instrument.

If you're using a soldering iron for assembly, here's



marker is absent on the CP2102, the CP2102 pin 1 orientation is identical to that of the CP2103. Correct pin 1

■ PHOTO 3. A correctly aligned CP210x will look like this with relation to the silkscreened U1 part designator. Note D1's odd and wider pin. The correct orientation of the 4.7  $\mu$ F capacitor (C1) is also visible in this shot.

something to consider. To utilize the CP210x parts, you only need to solder nine of the CP2102's 28 pins and 14 of the CP2103's 28 pins. If you forego the LEDs in the CP2103 design, you only need to solder 10 of the CP2103's 28 pins.

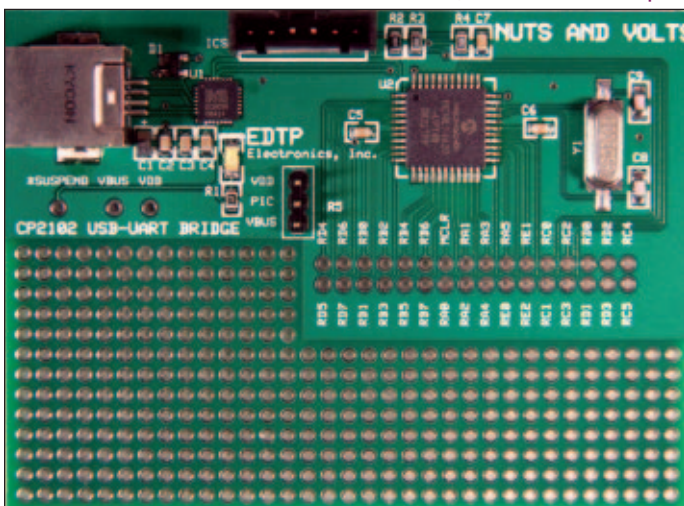
For those of you with hot air soldering systems, you're in for a treat. The CP210x parts just seem to grab the PCB pads and align themselves when the solder goes molten. In addition to the dot of solder on the ground

pad via, I coated the CP210x pads with a thin film of clear solder paste before mounting and soldering with the hot air machine.

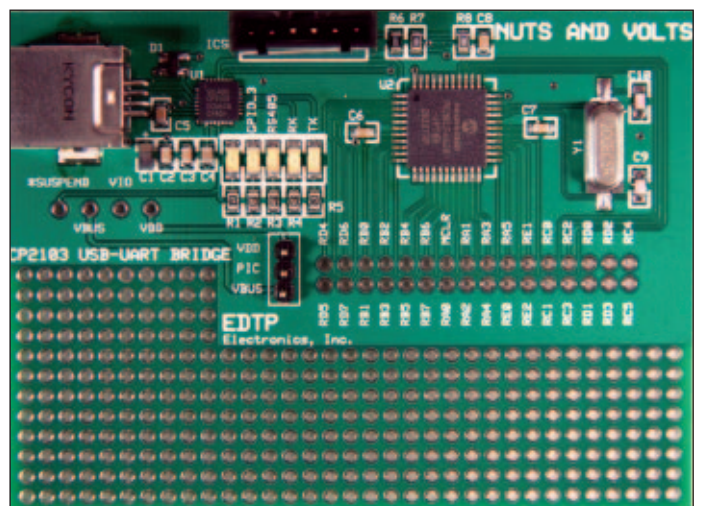
The PIC18LF4620 is a large target compared with the CP210x and is easily soldered into place using a hot air nozzle or a fine pitch soldering iron tip. The 0805-packaged resistors and capacitors are also relatively large components and are not at all difficult to mount and solder down. The same goes for the 1206-packaged LEDs, the SMT USB connector, and the crystal. If SMT soldering is foreign to you, Robert L. Doerr's SMT soldering "How To" in the January 2009 issue of *Nuts & Volts* is a good reference for those of you tackling SMT soldering for the first time.

In the midst of celebrating your soldering success with the CP210x and the PIC18LF4620, be sure to solder the USB connector shell tabs to their grounding pads. The SUSPEND, VBUS, VIO, and VDD termination points are intended to allow you to electrically mix these signals and voltages into circuitry you assemble in the breadboard area. If you decide to use the VIO feature, be sure to cut the solder side trace between the VDD and VIO

■ PHOTO 4. After designing the CP2103 board, I felt that I had to cover all of the CP210x bases and put this one together, as well. If you only need to replace an existing RS-232 interface with a USB connection, build this one up.



■ PHOTO 5. Everything you need in a USB-to-UART Bridge is here. If you need additional I/O, Dynamic Suspend, and RS-485 support, build this one up.





■ **SCREENSHOT 1.** If you look closely at the top most Serial Number field, you can pick out the original serial number (0001) in the string. Note also that the current VID and PID are incorporated into the string.

termination points.

As you can see in Photo 3, pin 1 of the SP0503BAHTG is larger than the part's other three pins. Orient it to place the larger and slightly offset pin 1 on the ground pad closest to the silkscreen designator *D1*. As C1 is a 4.7  $\mu$ F polarized tantalum capacitor, make sure you orient the positive terminal as shown in Photo 3.

Just in case you're missing the presence of the Microchip-standard RJ-11 ICSP jack, it's on the dongle. You can find the ExpressPCB file for the programming/debugging dongle in the download package for this set of projects on the *Nuts & Volts* website ([www.nutsvolts.com](http://www.nutsvolts.com))

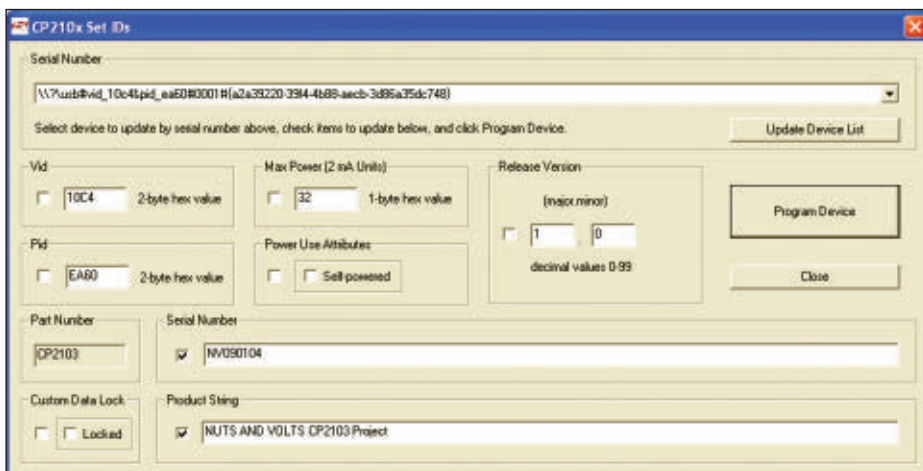
I don't know about you, but I'm ready to test. My fully assembled and yet to be tested CP2102 and CP2103 project boards are saying cheese in Photos 4 and 5, respectively.

## TESTING YOUR CP210X HARDWARE

This is where I used to punch out. Even when a typical USB interface contained a crystal, an EEPROM, and various glue components, it was relatively easy to put the hardware together. What seemed possible in the hardware became impossible in the firmware and host software. I have a good feeling that we are about to be triumphant. We have promising USB interface hardware and known good host software. There is no USB interface device firmware to write as it's all embedded in the CP210x hardware. With that, go to the Silicon Laboratories website (see Sources) and download the USBXpress Development Kit and the VCP driver.

Everything we will need to bring a CP210x online is contained within the USBXpress code. If you're feeling lucky and want to exercise your C++ and Visual Basic skills, you can use the USBXpress DLL to assemble some custom CP210x interface applications. If you're feeling lucky and can't spell USB, C++, or Visual Basic, use the factory supplied precompiled CP210x interface applications to set up your CP210x.

Much of the work needed to put a CP210x online can be done with the *CP210x Set IDs* application. For instance, in Screenshot 1 I changed the default CP2103 Serial Number of 0001 to NV090104. I also



customized the Product String. Note that the *CP210x Set IDs* application also allows the CP210x programmer to assign a PID and VID. After making the changes and clicking on the *Program Device* button, the new values were loaded into the CP2103's internal EEPROM. A moment later, Windows flashed the *Found New Hardware* bubble displaying the new Product String (NUTS AND VOLTS CP2103 Project). I then closed the *CP210x Set IDs* application and immediately reopened it. Sure enough, the updated Serial Number and Product String were displayed in the CP210x Set IDs window.

If you opted for the CP2103 project, you can invoke the *CP210x Port Read/Write* application to exercise the GPIO\_x LEDs. I used the write portion of the application to turn on all of the CP2103's GPIO\_x LEDs in Screenshot 2.

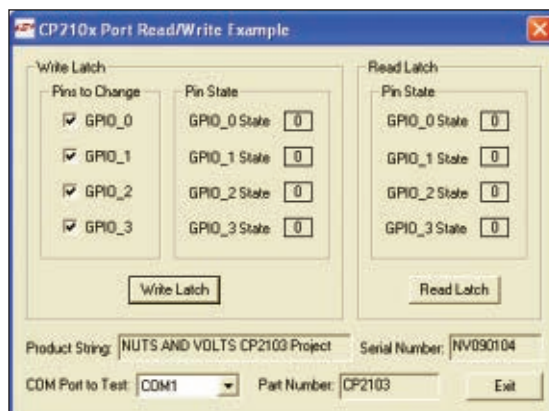
## FINAL CHECK

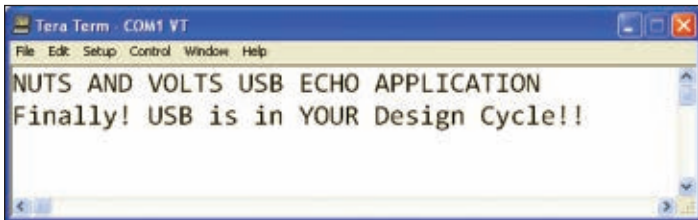
Obviously, if your CP210x hardware responds to the canned USBXpress applications, you've assembled your hardware correctly. The next step we must take is to write some simple code for the PIC18LF4620 that will echo characters across our new USB link.

According to the sales pitch, a CP210x USB circuit can be substituted for a legacy RS-232 serial circuit with no changes to the application code. That means that we should be able to use some time-tested PIC RS-232 code without modification.

Our PIC18LF4620 code will set the PIC18LF4620 EUSART baud rate for 57600 bps. We'll also configure the PIC18LF4620's interrupt subsystem to catch incoming characters and immediately push them back out. Our character generator is an instance of Tera Term Pro running

■ **SCREENSHOT 2.** The USBXpress factory-compiled application not only gives you control over the GPIO\_x LEDs, it verifies your device's Product String and Serial Number.





■ **SCREENSHOT 3.** The banner was generated by the PIC18LF4620. The echoed message below it was sent to the PIC18LF4620 via Tera Term Pro and the USB interface. Welcome to our house, USB!!

on a laptop personal computer.

The PIC18LF4620 code consists of an EUSART interrupt handler that buffers incoming characters and dispatches outgoing characters. The outgoing data is loaded into a transmit buffer under the control of the application code. Characters are retrieved from the receive buffer using a function called *rcvchar*. Our PIC18LF4620 echo application uses the *sendchar* function to load characters into the transmit buffer. The presence of characters in the receive buffer is discerned by executing the function *CharInQueue*. So, to echo incoming characters, we code up these statements:

```
while(! (CharInQueue()));
sendchar(rcvchar());
```

Powering up to a blank Tera Term Pro window is not desirable. So, let's force the PIC18LF4620 to transmit a banner message after the EUSART has been initialized:

```
printf("NUTS AND VOLTS USB ECHO
APPLICATION\r\n");
```

Now, let's put it all together. We want to initialize the PIC18LF4620 EUSART, display a banner and run our echo code forever:

```
Void main(void) {

    unsigned int x,i;
    init();           //init the EUSART
    printf("NUTS AND VOLTS USB ECHO
APPLICATION\r\n");
    for(i=0;i<0x3FFF;++i)    // kill time
        ++x;

    do{
        //wait for incoming character
        while(! (CharInQueue()));
        //echo incoming character
        sendchar(rcvchar());
    } while(1);
}
```

Don't worry about the code you don't see here as you have access to the entire USB echo application in the download package. I compiled the USB echo application with HI-TECH C PRO for the PIC18 MCU Family. The compiled code was programmed into the PIC18LF4620 using the RJ-11 programming/debugging dongle assembly in the download package and a brand new Microchip ICD3. From the looks of the messages contained in the Tera Term Pro window you see in Screenshot 3, we've added an embedded USB interface to our Design. **NV**

## SOURCES

Silicon Laboratories — [www.silabs.com](http://www.silabs.com)  
PCP2102; CP2103; USBXpress

HI-TECH Software — [www.htsoft.com](http://www.htsoft.com)  
HI-TECH PICC-18

Microchip — [www.microchip.com](http://www.microchip.com)  
PIC18LF4620; MPLAB ICD3

ExpressPCB — [www.expresspcb.com](http://www.expresspcb.com)  
CP210x Printed Circuit Boards

■ Fred Eady can be contacted via email at [fred@edtp.com](mailto:fred@edtp.com).

Order online at:  
[www.melabs.com](http://www.melabs.com)

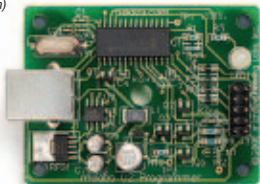
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# SMILEY'S WORKSHOP

AVR MICROCONTROLLER: C PROGRAMMING - HARDWARE - PROJECTS

by Joe Pardue

Get started now with this series!  
Joe's book & kit are available in our  
webstore at [www.nutsvolts.com](http://www.nutsvolts.com)

## PART 8: Interrupts, I/O Registers, and the Butterfly Joystick

In Part 6, we used the Butterfly joystick with library functions to implement a menu navigation system but didn't go into any details of how the joystick worked. This month, we will use the joystick as an introduction to AVR interrupts and I/O registers.

### The Butterfly Joystick Hardware

The original joystick was an early aircraft control lever that allowed the pilot to maneuver the plane left, right, up, and down. Fighter planes added a center button to fire machine guns. The Butterfly joystick — like many menu navigation devices found on remote controls and cell phones — has five positions: UP, DOWN, LEFT, RIGHT, and PUSH (see Figure 1). Manufacturers, of course can't know which direction the user will orient their device, so they label them A, B, C, D, and Center (for PUSH) as in Figure 2, which correspond to pins numbered as in Figure 3

The Butterfly orients these pins and connects them to five of the ATmega169 port pins as in Figure 4.

Now that we've got the joystick all wired up, how does the Butterfly know when a joystick event occurs?

### Interrupts In General

In microcontrollers, we typically use either polling or interrupts to check to see if an event has occurred. Polling checks periodically to see if an event has happened. For instance, in the loop in main() we might check pin 6 to see if the voltage is +3 or 0 and, depending on the state, do one thing or another. If the microcontroller hardware is designed so that pin 6 can be used to interrupt the program, then we don't have to poll the pin. We can set the software so that when the pin state changes — say, falling from +3V to 0V — an interrupt function will be called automatically.

Interrupts on microcontrollers are like interrupts in daily life. The telephone interrupts your activities by its insistent ringing. Imagine how it would be if you had to poll the telephone to receive calls. Periodically, you'd pick up the receiver and say 'Hello, anybody out there?' and your caller would shriek, 'I've been waiting for an hour! Why don't you check your phone every five minutes like a normal person?' The ring of the phone interrupting workflow is annoying, but if someone wants to tell you that your garage is on fire, you want to know about it immediately.

Microcontrollers respond to interrupts much like you would.

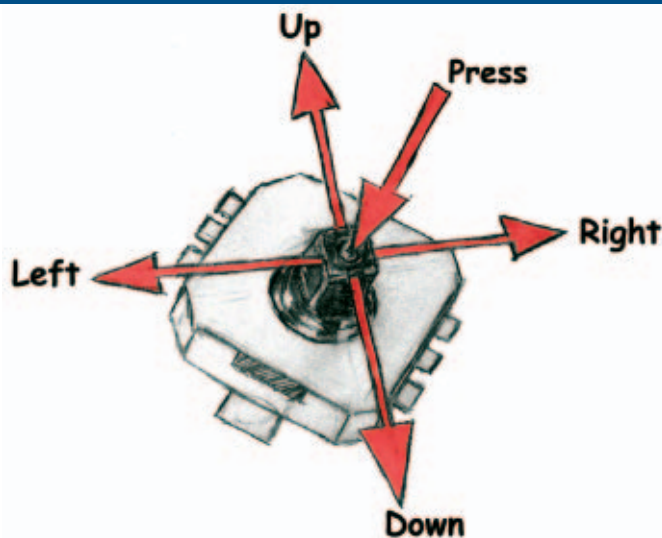
Maybe you are reading a book and the phone rings. You use your fingernail to mark the line you were reading and dog-ear the page before closing the book (librarians everywhere groan). Then, you answer the phone, and when the call is finished and you've put out the fire in your garage, you can refer to the desecrations to your book and go right back to where you left off.

From the hardware perspective, an interrupt causes the microcontroller to stop what it is doing, store sufficient data so that later it can get back to what it was doing, look to see which interrupt happened, run the interrupt code, and when finished, restore the machine to its state before the interrupt occurred using the previously stored data.

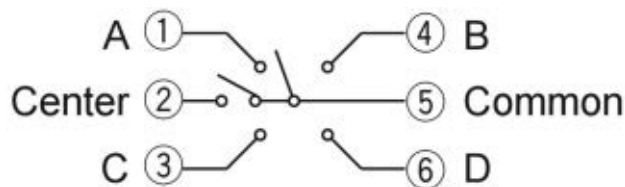
### Potential Interrupt Bug 1

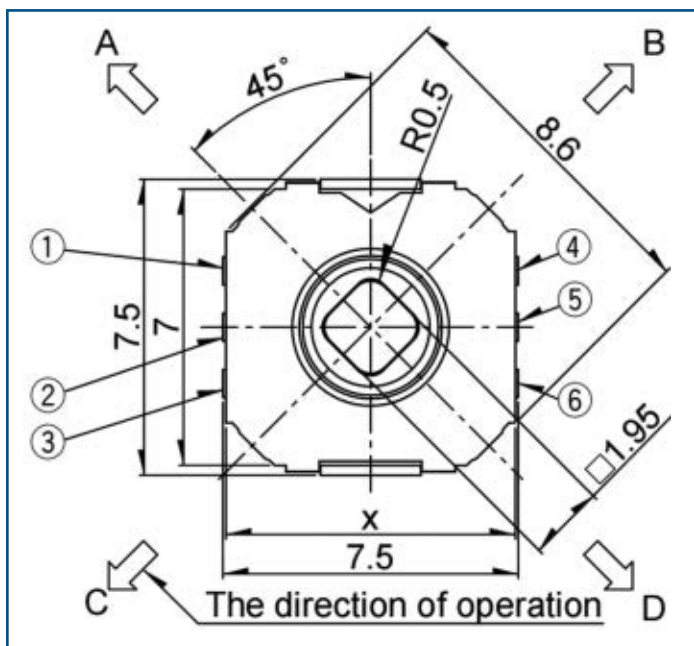
Interrupts are great, but they provide an avenue for

■ FIGURE 1. Butterfly joystick with five button positions.



■ FIGURE 2. Joystick schematic.





some particularly pernicious bugs. For example, your code is reading an integer from memory; an integer is made of two bytes. The code gets the first byte, then is stopped by an interrupt that changes the value of that very same integer before returning control to the part of the code that was reading it, which then gets the second byte of the integer. The integer will be wrong because it is made from half of the pre-interrupt value and half from the post-interrupt value. The crazy-making debugging problem is that the interrupt can happen at any time; maybe only rarely during the integer read. Your system can run like a champ and then lock up for no apparent reason. You don't want this kind of bug in your pacemaker. So you prevent it by disabling interrupts before reading variables that can be changed by interrupts, and then re-enabling them after you've got the correct number.

Another problem with interrupts changing variables can occur when you have the variable in a section of your code that looks to the compiler optimizer like it is not being used. The optimizer has various rules to search around to see if a

## C Knows Nothing About Interrupts

It is important to realize that the C programming language knows nothing about interrupts. C is machine independent — interrupts are machine dependent. Even different versions of the same machine — such as the AVR — may handle interrupts differently. Also, different compilers for the same microcontroller will often have different ways to use interrupts. We are fortunate to have the free WinAVR tool set with the GCC avrlibc to handle some of the more gory details, though it will get pretty gory anyway.

## A Quick Look At Registers

The AVR is a very flexible device and many of its features have several different ways they can be used. For instance, the ATmega169 I/O pin that we will be using for our UP selection in the joystick can be set up to be used in one of various ways: as either input or output; with or without an internal pull-up; it can be turned off (tri-stated) to remove it from the circuit or work for PWM output compare; or it can be used as an input interrupt. Other pins may be even more complex in their possible uses, but since each can only be used in one of its many possible configurations, the AVR must keep track of how it is supposed to be used. Setting bits in a special set of I/O registers to configure and keep track of various possible states does this.

AVR registers are eight bit memory locations that can be quickly accessed by the CPU. The AVR sets aside 64 I/O and 160 Extended I/O Registers in memory locations that can be used for peripheral configuration and state flags. The ATmega169 uses over 100 of these registers. Each of these

registers is named and may have two to eight named bits for each. As usual for microcontrollers, the names may be cryptic and confusing. This provides us with a bewildering excess of riches. You can see the list on page 341 of the ATmega169 data book — pretty scary, isn't it? But, relax because we won't have to memorize any of the details. Over time, we will carefully set up each register only when it is needed for a particular application and once we get

Direction	Port-bit	Joystick Pin
UP	PB6	A
RIGHT	PB7	B
LEFT	PE2	C
DOWN	PE3	D
PUSH	PB4	CENTER

Pin Change Interrupt	Port B Pin
PCINT15	PIN7
PCINT14	PIN6
PCINT13	PIN5
PCINT12	PIN4
PCINT11	PIN3
PCINT10	PIN2
PCINT09	PIN1
PCINT08	PIN0



that AVR feature working properly, we will consign the register and bit states to header files hidden behind some easy to remember names — well documented and carefully locked away in a tested library. The earlier Workshops hid all this in libraries, and there will be many libraries to come. In the meantime, it will help us to understand what is going on if we get an overview of this I/O register/bit concept.

## Setting Up External Interrupts Using The ATmega169 And avrlibc

To enable the joystick interrupts, we will need to set bits in four registers. We will see how to do this for three progressively simpler ways. The first is the most like a professional C programmer would do it — using the datasheet acronyms and bitwise operators which can be a bit cryptic for a novice. The second is a little simpler and hides the bitwise operations behind a macro. The third and simplest expands the acronyms to spell out the full register and bit names. In this Workshop, we will show the details only for the EIMSK (External Interrupt Mask Register), but the source code shows this for all used interrupts.

### External Interrupt Mask Register

We set the PCIE0 and PCIE1 (Pin Change Interrupt Enable 0 and 1) bits to enable PCINT15..8 which are the upper eight Pin Change Interrupts and are associated with the Port B pins 7..0 in the ATmega169 as shown in Figure 5.

The first way to do this is to use the register and bit acronyms listed in the io.h header file:

```
// Least verbose - most usual C like
EIMSK = (1<<PCIE0) | (1<<PCIE1);
```

If you remember the bitwise operators from Workshop 4 and know that in the header file that PCIE0 is defined as 7 and PCIE1 is defined as 6, you will see that this sets bit 7 and bit 6 in the EIMSK register. This register is shown on page 78 of the ATmega169 datasheet (see Figure 6).

A slightly easier way would be to define a macro for the bit shift operators to set the bits:

```
#define setBit(value1,value2) value1 |=(1<<value2)
```

A macro is a preprocessor directive that causes the “compiler to substitute one set of characters with another set. This can help simplify things in that you can substitute a simpler string of text for something more difficult. We can hide the bitwise operators that shift and the OR bits.

Anywhere the compiler sees:

```
setBit(value1,value2)
```

It will substitute:

```
value1 |=(1<<value2)
```

Bit	7	6	5	4	3	2	1	0	
	PCIE1	PCIE0	—	—	—	—	—	INT0	EIMSK
Read/Write	R/W	R/W	R	R	R	R	R	R/W	
Initial Value	0	0	0	0	0	0	0	0	

■ FIGURE 6. The EIMSK Register.

For instance, if we use:

```
setBit(EIMSK,PCIE0)
```

The compiler will write:

```
EIMSK |= (1<<PCIE0)
```

Finally, we will try to make this even easier by expanding the acronyms:

```
#define ExternalInterruptMaskReg EIMSK
#define PinChangeInterruptEnableBit0 PCIE0
#define PinChangeInterruptEnableBit1 PCIE1
```

and using:

```
// Most verbose
setBit(ExternalInterruptMaskReg,
      PinChangeInterruptEnableBit0);

setBit(ExternalInterruptMaskReg,
      PinChangeInterruptEnableBit1);
```

You can see how this is done for all five registers by looking at the initJoystick() function in the source code in the Workshop8.zip (refer to the download link at the end of this column.)

### Enable Global Interrupts

SREG — Status Register

I-bit — Global Interrupt Enable

Setting the I-bit enables all interrupts and clearing it disables them. After a hardware interrupt occurs, the I-bit is cleared so that no further interrupts can occur while the interrupt service routine is running. When the interrupt finishes, the interrupt returns with the RETI instruction that will reset the I-bit, thus enabling further interrupts.

### External Interrupt Flag Register

EIFR — External Interrupt Flag Register

PCIF0 — Pin Change Interrupt Flag 0 Bit

PCIF1 — Pin Change Interrupt Flag 1 Bit

If PCIF0 is set, when any PCINT7..0 pin changes state and if the I-bit is set and the PCIE0 bit is set in EIMSK, then an interrupt request is triggered so that the associated interrupt service routine will be run. The same is true for the PCIF1 bit and the PCINT15..8 pin changes.



## Pin Change Mask Registers

PCMSK0 — Pin Change Mask 0 Register

PCMSK1 — Pin Change Mask 1 Register

The PCMSK0 register has PCINT15 to PCINT8 bits, each of which when set to 1 enables the pin change interrupt for the corresponding I/O pin.

## Interrupt Service Routines

When the ATmega169 receives an interrupt, it loads the address of an Interrupt Service Routine from the Interrupt Vector Table. A 'vector' is just a fancy way to say address. There are 23 vectors shown on page 47 of the datasheet but we will only be using vectors 3 and 4 for the PCINT0 and PCINT1 interrupt.

```
// Pin Change Interrupt 0
// Interrupt Service Routine
ISR(SIG_PIN_CHANGE0)
{
    pinChangeInterrupt();
}

// Pin Change Interrupt 1
// Interrupt Service Routine
ISR(SIG_PIN_CHANGE1)
{
    pinChangeInterrupt();
}
```

So, if any of the joystick pins change then the `pinChangeInterrupt()` function will be called by ISRs. When an interrupt is triggered, the I-bit is cleared and no further interrupts will be serviced until the ISR exits — so interrupts should to be serviced as rapidly as possible (there are exceptions, but we won't deal with those yet). If the interrupt requires some serious processing to be done, just set a flag, exit the interrupt, then look for the flag in the infinite loop in `main()` and call a regular function that can be interrupted.

## Servicing The Joystick Interrupt

In the `pinChangeInterrupt()` function, we will not use any simplifying macros. We first load the ports B and E pin pattern into an eight-bit variable:

```
uint8_t buttons;

buttons = (~PINB) & PINB_MASK;
buttons |= (~PINE) & PINE_MASK;
```

Note that the pin state is 0 for the pin that got changed. The `PINB_MASK` makes sure that only valid joystick pins are looked at and `PINB` contains the state of the pins on port B. Since we are ANDing it with the mask, we use the `~` operator to invert the levels, changing 0 to 1. You may want to review bitwise operators in Workshop 6 and do a little pencil and paper computing if this isn't clear.

After we get the pin states in the button variable, we check for the key:

```
// Which key was pressed?
if (buttons & (1<<BUTTON_A))
    key = KEY_UP;
else if (buttons & (1<<BUTTON_B))
    key = KEY_DOWN;
else if (buttons & (1<<BUTTON_C))
    key = KEY_LEFT;
else if (buttons & (1<<BUTTON_D))
    key = KEY_RIGHT;
else if (buttons & (1<<BUTTON_O))
    key = KEY_PUSH;
else
    key = KEY_INVALID;
```

If there is a valid key present, we load it in the global `joystickInput` variable and set the global `joystickChanged` to true:

```
// Is there a valid key?
// Load it in the global variable joystickInput
// And set the global variable joystickChanged
if(key != KEY_INVALID)
{
    joystickChanged = 1;
    joystickInput = key;
}
```

This works much like the Menu in Workshop 6, but this time we hide the state machine in a library and show the joystick hardware setup and use. You can download the source code and a supplement: *C Programming — Out of the Nest* for this month's article from [www.nutsvolts.com](http://www.nutsvolts.com) or [www.smileymicros.com](http://www.smileymicros.com). **NV**



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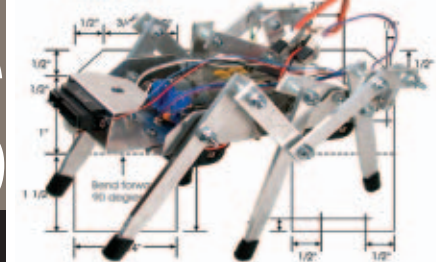
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■ BY VERN GRANER

## ROBOTICS ON A BUDGET: BUILDING BOTS THAT DON'T BREAK THE BANK

WITH THE RECENT HEADLINES ABOUT bailouts, layoffs, and global recession, it's pretty obvious there's going to be some belt-tightening in the average household. For many of us, hobbies are one of the first things to get cut out when there are bills to pay. At the very least, we want to look a bit harder at our purchases and see if we can draw a firm line between our "wants" and our "needs." Of course, all work and no play can result in the axe-chopping of a hotel door in the wilderness (REDRUM!), so we need to find *some way* to keep "play" in the game! That means it's time to go hunting for some low-cost (maybe no cost?) robotic fun!

### THE THRILL OF THE CHASE

Most towns have a thrift store or other shops that recycle and resell clothes, toys, household wares, and the like. In many cases, you'll find these stores carry lots of useful electronics that can be picked up for a song. Typically, they are camouflaged as broken electronic toys, answering machines, computers from previous

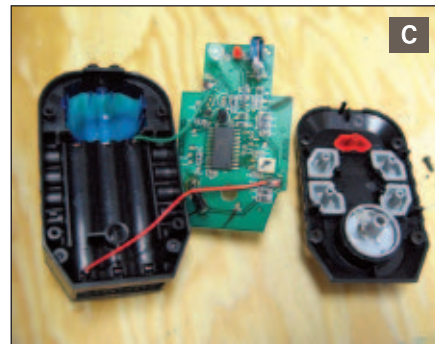
decades, telephones, boom-boxes, and other consumer electronics. It can be fun (and frugal) to go hunting through the shelves for these hidden parts caches. You may be surprised how many parts you can scrounge up with as little as \$10 (Figure 1).

For example, many thrift stores have old ink-jet (and sometimes dot matrix) printers. These are a great resource for harvesting parts! Gears, motors, belts, sensors, buttons, LCD displays, and all kinds of electronic

components can be extracted with a bit of time, some hand tools, and a soldering iron. The same thing can be said for electronic "action" toys. These have been known to contain sound generators, LEDs, speakers, battery holders, and even infrared transceivers (Figure 2). Also, many of the thrift stores I've visited really have no idea how to price the electronics and so you may be able to fill an entire shopping cart for as little as \$20!

■ FIGURES 1A, 1B, and 1C. Examples of some thrift shop finds including switches in an old joypad, a human hand analog that seems to be crying out to be upgraded with a servo, and the "gripper" used in last month's column on pneumatics.





■ FIGURES 2A, 2B, and 2C. The LEGO Spybotics remote control module sports a nice AAA battery box, IR transmitter, pushbuttons, and an LED.

## HARD DRIVE HARVEST

One item that is almost always able to yield some useful parts after being opened up is the venerable computer hard drive. Some older drives (especially older 5-1/4" MFM/ST-506 type drives, and some 5-1/4" floppy drives) contain very nice stepper motors (Figure 3), gear trains (Figure 4), sensors (Figure 5), and other useful bits for the hobbyist. If you can't find this vintage of hard drive, don't despair! Similar parts can be found in most CD/DVD ROM drives.

Most all modern 3.5" hard drives (Figure 6) contain recyclable and useful parts including very powerful neodymium magnets, .100" jumpers, precision screws, bearings, and other hardware (Figure 7), as well as the shiny data platters. Disassembly is simple, quick, and fun and the parts yielded are usually useful and worth your time to harvest.

Another item I hunt for at thrift stores is the oft-maligned wall wart (given its name due to its appearance

as an unsightly growth on the wall). It always seems I need a specific voltage, amperage, plug type/size, or gender that I don't have on hand. I've been known to walk out of a thrift store with 10 or more of these babies (Figure 8). This way, I can always dig out an acceptable, portable power supply for a small experiment.

In the Austin, TX area, wall warts at thrift stores typically go for between \$0.50 and \$2.00. You can also often discover orphaned "brick style" power supplies commonly used to power laptop computers. These tend to be higher voltage/amperage and can sometimes produce multiple supply voltages so they have the potential of replacing a couple of wall warts. Keep your eyes peeled (and possibly take a magnifying glass with you) as the writing on these can be very small.

## KEEP IT ON THE DOWN-LOW!

In most cases, my idea of "low cost" is below \$100. I know this will

probably be different for each person, but I stay with this number for two reasons. One: sub \$100 purchases are less likely to be picked up on the radar by a "significant other." Two: if you are discovered, it's easier to recover from because it's about the same cost as a nice dinner out for two.

So, with \$100 as the benchmark, can we really buy much in the way of "new" robotics parts or projects? The answer is a resounding YES!

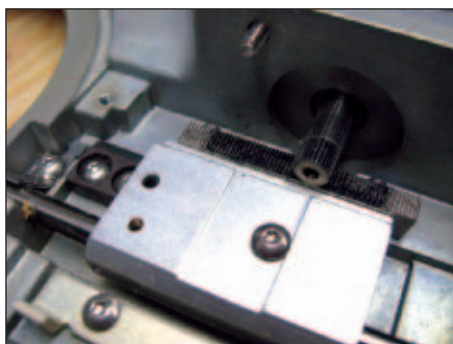
Compared to a couple decades ago when a useful robotic training system cost thousands of dollars (think HERO-1), today's robotics offerings are immensely powerful with exceptional price/value ratios. For example, Parallax offers a complete two-wheel robot kit with their ever-popular BASIC Stamp II at its heart that retails for \$99.99 (careful online shopping can nab one for \$75 or less!).

The "Scribbler" (Figure 9) is a real programmable robot with the ability to move, use sensors, evaluate inputs, make sounds, and even draw pictures (hence the name). It also includes a

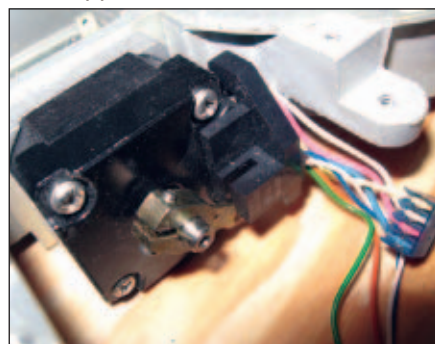
■ FIGURE 3. This is what's left after removing the platters, platter drive motor and circuit board from a dead ST-506 hard drive.



■ FIGURE 4. The stepper motor drives this nice metal platform that used to position the hard drive's magnetic heads.



■ FIGURE 5. On the other side of the platform, an optical sensor with an adjustable interrupter is affixed to the stepper motor's shaft.





■ FIGURE 6. A typical "modern" IDE hard drive ready for disassembly.



free graphical programming interface, as well as a comprehensive teaching curriculum to help newcomers learn robotic principles. Of course, since it is powered by the venerable BASIC Stamp II microprocessor, it's possible to skip the entry level stuff and program the unit directly using the free IDE.

There are similar offerings from a variety of companies with some more "focused" kits that are in the sub \$20 range. These usually explore a facet of basic robotics such as sensors or motors (see Resources for a list of low cost robotics kits). A good example of this is the Light Spider Robot Kit that sells for \$12.25 (Figure 10) or the Aqualocator Robot Kit that sells for \$24.95 (Figure 11). These "single purpose" robots are a good place to learn and experiment with facets of robotics without breaking the bank.

## ULTRA LOW COST MICROCONTROLLERS

Though I am (and continue to be) a big fan of Parallax parts and their incredible support, there are some very interesting offerings from other companies that have been in the microcontroller game for quite a while. For example, the UK company Revolution Education Ltd. markets the PICAXE series of microcontrollers. Their PICAXE-08M is an eight-pin chip that sports five I/Os, three analog inputs, and is programmed in a dialect of Basic. I found this chip being offered on the SparkFun website for \$3.95 (Figure 12). In fact, a complete kit that has a socket for the PICAXE-08M microcontroller chip, programming jack, and prototyping area was selling for \$4.95 (Figure 13).

A 3.5" stereo (i.e., Tip-Ring-

Sleeve) jack is required to connect to the programming port and you can buy the DB-9 to 3.5" cable pre-made from SparkFun for about \$7. However, to keep things cheap I was able to make one from a recycled serial mouse (removed the cable with the correct gender DB-9 connector) and a broken pair of portable headphones (I clipped the cable and used the 3.5" stereo plug). So all tolled, that's a fully functional prototyping kit for a microcontroller chip programmed in Basic for less than \$10. To me, it's astounding that so much power and versatility now resides in the same footprint as a classic 555 timer!

## OKAY, SO HOW ABOUT SOME NO-COST IDEAS?

So, the pennies have been pinched, the numbers have been crunched, and it turns out that unless you want to be programming your projects by candlelight, you may sadly have to forgo any more expenditures in the electronics/robotics department for a while. With a budget of effectively zero, is there any way to continue in your hobby?



■ FIGURE 7. The parts of a 3.5 inch hard drive after disassembly. (Time to complete this was only about 30 minutes).

Past experience shows that it is possible to continue to experiment (and even build projects) if we apply a bit of imagination. Let's start by exploring some no-cost strategies for electronics and robotics projects.

## GET RE-EXCITED!

Quite a few years ago (I shudder to think), I was a typical "starving artist" singer/songwriter with big dreams of rock and roll stardom. At loose ends during the day and between gigs, I would head on down to the local music shops and wander the isles examining the newest breakthroughs in musical equipment. I would often find myself salivating over some hot new MIDI instrument, effect processor, recording system, sound processor, or PA system gadget. It was particularly depressing when I would return home empty-handed as times were tough and I couldn't afford to buy any of these

■ FIGURE 9. The Parallax Scribbler robot.



■ FIGURE 8. A collection of wall wart and "brick" style power supplies picked up on shopping trips to the thrift store.





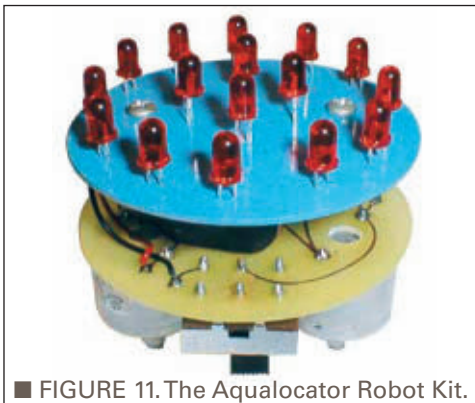
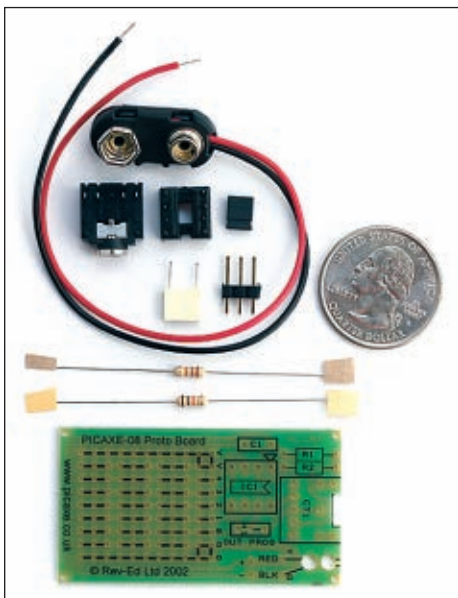
■ FIGURE 10. The Light Spider Robot Kit.

cool toys. It was in those days that I discovered a cure for the "new gear blues" that continues to work for me to this day.

Here's the trick: I would go back and re-read the advertising literature for the equipment that *I already owned*. Reading through the lists of capabilities, the marketing hype, and the typical configurations of the stuff I already had would in many cases rekindle the excitement I felt when I first opened the box!

Now with the Internet, it's possible to pull up information, specifications, and marketing literature for just about *any* part or device you have lying around. A good place to start "prospecting" for the gold you may already own (but may have forgotten about) is one of those junk boxes in the closet or even hiding in plain view collecting dust on a shelf (Figure 14). Punch a few model numbers into Google and see if you can remember why you

■ FIGURE 13. The PICAXE eight-pin proto kit from SparkFun Electronics.

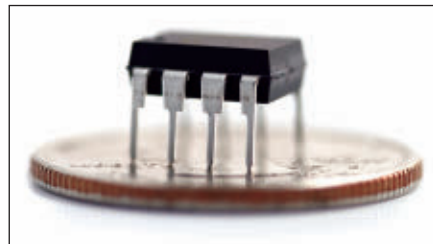


■ FIGURE 11. The Aqualocator Robot Kit.

bought these things in the first place. Sometimes we forget the excitement that drove the original purchase, but it can come back to you with a little bit of reading.

## NOW, WHY DIDN'T I THINK OF THAT!?

You may find your searches lead to websites with pictures and videos of some new and interesting way to combine or use the very devices you already have. A couple of months back, I was wanting to bring a project to the Robot Group's weekly meeting "Show and Tell" event. I did a few searches on Google and found a cool video blog where the Parallax GPS and a BASIC Stamp II were combined to make a rudimentary GPS system (see Resources). I had purchased a Parallax GPS unit a while back for a Magellan robot I was contemplating, and a quick search through my microprocessor box turned it up in its anti-static bag, never used. A bit more digging turned up a BASIC Stamp II, a Board



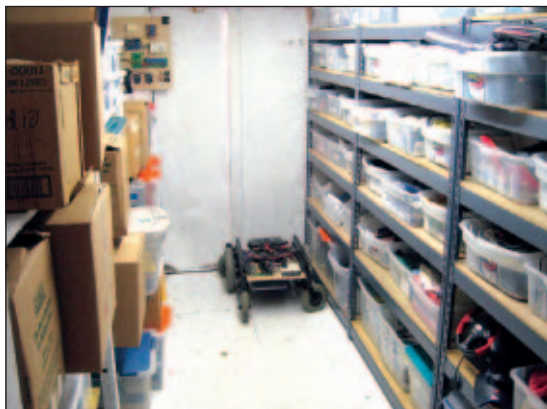
■ FIGURE 12. The PICAXE-08M — an eight-pin chip that sports five I/Os, three analog inputs and is programmed in Basic.

of Education, and a two line serial LCD display (among other parts) just sitting in a box. Inspired by the video, I combined my pieces in a similar way to recreate this unit. By the next day, I had a simple GPS display sitting on the dashboard of my car as I headed to the meeting. Total equipment cost: zero dollars.

After this success, I remembered watching an episode of "Prototype This!" on The Discovery Channel where Joe Grand from Grand Design Studios used a Stamp to join an RFID reader to a speech synthesizer to create a neat "restricted access" system. After a bit of digging in my junk boxes, I discovered I had all the parts he used in that design. So, I was able to make another complete project using existing parts I already owned, just combined in a way I hadn't done before (Figure 15).

## VIRTUAL ROBOTICS

Another idea for zero cost involves *virtual* robotics projects. I went over this in-depth in the March 2008 issue of *Nuts & Volts*. It has quite a bit of information about how to experiment with robotic simulations that cost nothing to download and run on your computer. As a subscriber to *Nuts & Volts*, you are able to use the on-line service to read back issues for *Nuts & Volts* for free! See the Resources section for a link to the on-line edition of the magazine.



■ FIGURE 14. The junk bins in my shop that contain the bits and pieces collected over three and a half decades of electronics and robotics fun.



## PLANNING IS FREE!

While you're perusing the Internet, I think it's important to remember that research and planning cost you nothing. All you need to do is bookmark the interesting pages and/or spend some time drawing up your ideas — either in a CAD program or with something as humble as a notebook and pencil. I spend lots of time doodling drawings of devices that sometimes don't come to fruition (yet) and others that do (check out the December 2007 issue of *Nuts & Volts* to see how one of my sketches became a 20 foot tall ping-pong ball shooting robot). I've placed a couple of useful links in Resources that you can use to get inspired to start planning your next project (don't miss the "Let's Make Robots" site where members share their latest creations!).

## KEEP YOUR CHIN UP!

I hope this article helps to inspire you to not let economics defeat your interest in electronics and robotics. As Theodore Roosevelt once said, "Do what you can, with what you have, where you are." This is good advice for those faced with a sudden drop in funding. Necessity, though normally just famous as the mother of invention, may masquerade as your muse inspiring newfound

## RESOURCES

- PICAXE chip and protoboard from SparkFun: [www.sparkfun.com/commerce/product\\_info.php?products\\_id=8321](http://www.sparkfun.com/commerce/product_info.php?products_id=8321)
- Joe Grand and Bre Pettis weekend project video on GPS: [http://blog.makezine.com/archive/2007/07/integrate\\_lcd\\_and\\_gps\\_mod\\_1.html](http://blog.makezine.com/archive/2007/07/integrate_lcd_and_gps_mod_1.html)
- Low cost robotics kits: [www.chaneyelectronics.com/products/robots](http://www.chaneyelectronics.com/products/robots)  
[www.parallax.com/scrabble](http://www.parallax.com/scrabble)  
[www.goldmine-elec.com](http://www.goldmine-elec.com)  
[www.pololu.com](http://www.pololu.com)
- The show "Prototype This!" featuring Joe Grand of Grand Design Studios: [www.discovery.com/prototypethis](http://www.discovery.com/prototypethis)
- The RFID reader from Joe Grand's website: [www.grandideastudio.com/portfolio/rfid-reader/#more-65](http://www.grandideastudio.com/portfolio/rfid-reader/#more-65)
- The "Virtual Robotics" column from March 2008: <http://nutsvolts.texterity.com/nutsvolts/200803>
- "The PONGINATOR" column from December 2007: <http://nutsvolts.texterity.com/nutsvolts/200712>
- Planning and inspiration links: <http://letsmakerobots.com>  
<http://hackaday.com>  
<http://forums.parallax.com/forums/default.aspx?f=21>
- The *Nuts & Volts* Online Forum: <http://forum.servomagazine.com>
- The Robot Group, in Austin, TX: [www.TheRobotGroup.org](http://www.TheRobotGroup.org)

creativity! Remember, you're not alone. There are thousands of hobbyists out there that share your interest, your hardships, and your triumphs. Why not take a moment to come by the *Nuts & Volts* online forum and meet some of them? In the meantime, feel free to let me know what you're thinking. You can always reach me by email at [vern@txis.com](mailto:vern@txis.com). **NV**



■ FIGURE 15. The Talking RFID Access Control demonstration system I built for "Show and Tell" at The Robot Group meeting in Austin, TX.

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■ BY L. PAUL VERHAGE

# BALLOONSAT MINIS: ONE SMALL STEP FOR A PICAXE, ONE GIANT LEAP FOR BALLOONSAT DESIGN

A STUDENT'S FIRST INTRODUCTION TO NEAR SPACE normally includes BalloonSats and a neat datalogger like the Hobo by OnSet Computing. If, however, you are ready to try BalloonSat avionics a bit beyond that, I have the perfect solution: BalloonSat Minis. These BalloonSat flight computers don't contain nearly as much data memory as a Hobo, but the Minis are simple printed circuit board (PCB) kits for a BalloonSat class to assemble and program. BalloonSat Minis are flexible in their ability to log data and they can operate servos, cameras, and experiments — not just record data. They can even monitor cosmic rays with an Aware Electronics RM-60 Geiger counter. BalloonSat Minis are one of three new BalloonSat flight computers designed during my first semester of grad school. You will read about these other BalloonSat avionics in coming months, but let's start with the Minis.

## CAPABILITIES OF THE BALLOONSAT MINIS

At the heart of a BalloonSat Mini is a PICAXE-08M — the closest thing to silicon popcorn that I have found. At less than \$4 a pop and

■ This BalloonSat Mini 3 is designed to operate a servo with the male header hidden behind the two visible receptacles. Alternatively, the servo header can record data from a third sensor.

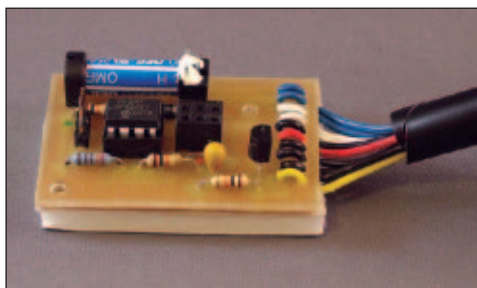
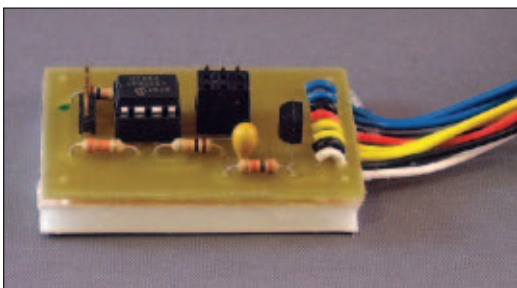
programmable to the tune of 256 bytes, these microcontrollers are the ultimate tasty addition to any electronics project. The '08M shares program space with its data storage space, so you'll want to keep your program small to maximize its data collection ability. The 08M's limited memory creates a challenge for students as they design the avionics software for their BalloonSat. However, this challenge is not too tough, as even this old dog wrote an

acceptable program for a Mini that left around 180 bytes of storage available for data. That's enough to record two sensor voltages every minute for the BalloonSat's entire ascent.

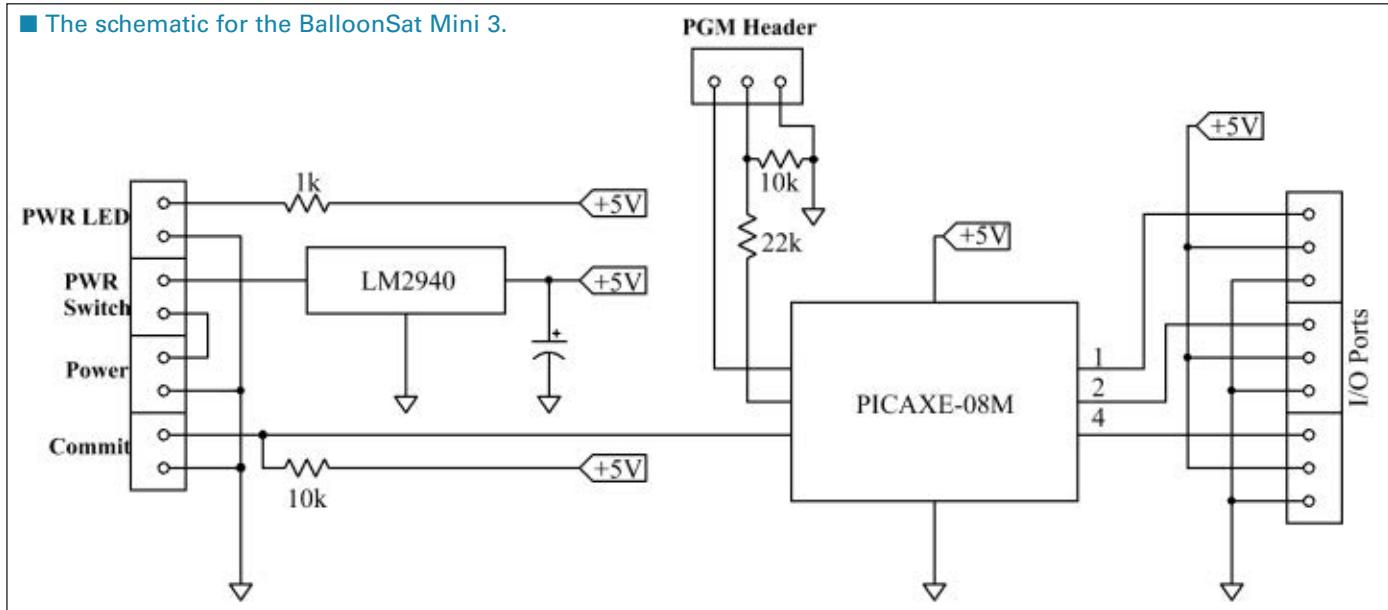
Minis operate from a nine volt battery and contain an external power switch, power indicator LED, and commit pin. The battery choice keeps them cheap to operate while the external components (switch, LED, commit pin) allow students to power up and launch their BalloonSat without having to open it up.

The only difference between the two flavors of

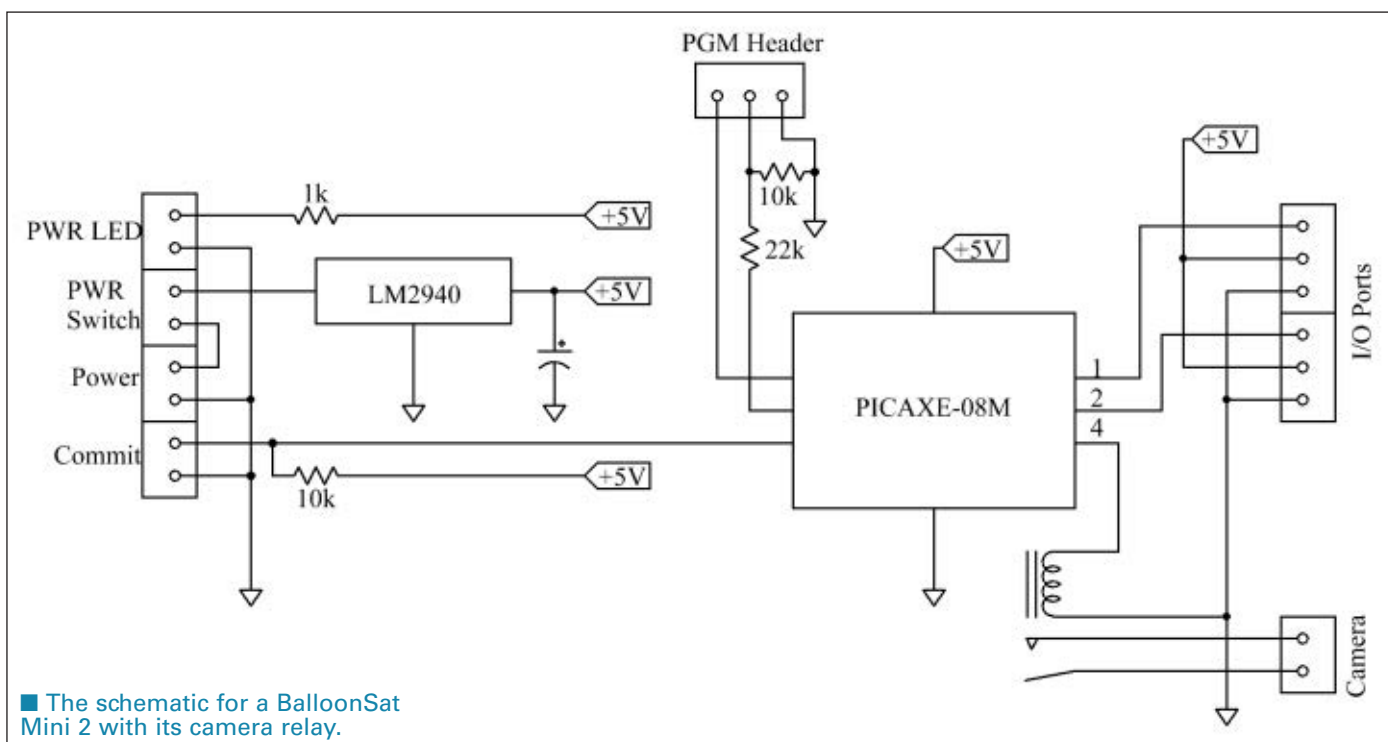
■ This Mini 2 is designed with photography in mind. Its reed relay can easily take on a near space mission to reliably trigger a camera inside the BalloonSat.



■ The schematic for the BalloonSat Mini 3.



■ The schematic for a BalloonSat Mini 2 with its camera relay.



Minis is the configuration of the third I/O port. The Mini 3 has three I/O channels, all capable of digitizing sensor voltages at either eight or 10 bits of resolution. I recommend using female receptacles for the first two I/O ports and a three-pin header for the third. That way, a servo can easily connect to the Mini 3. However, even with its three-pin header, a third experiment can still be connected to the Mini 3; it just needs a connector identical to the ones used on servos.

The Mini 2 has two I/O channels since its third I/O port operates a camera via a reed relay. I recommend using female receptacles for both I/O ports, although there isn't any reason one couldn't use a male header instead. A modification like that would make the Mini suitable for one sensor, a servo, and a camera. As you can see by their schematics, the Minis are pretty simple in design and have a low parts count. That's because they make

heavy use of the capabilities built into the PICAXE-08M.

## ASSEMBLING A BALLOONSAT MINI

There's nothing tricky about soldering the BalloonSat Minis together. Since they are single-sided boards, there's one jumper wire to install on both designs. Check out the diagrams for the placement of parts.



## SOLDERING

Always bend a component's leads before you insert it into the PCB. Stores like Jameco sell bending jigs that are perfect for getting them bent correctly the first time. It's usually easier to assemble a PCB if you solder the lowest lying components first. So in this case, begin by soldering the jumper wire. The most convenient jumper wire is a cut resistor lead. If you have one lying around — great. If not, then solder a resistor to the PCB first and then trim

its leads to get your jumper wire.

After installing the jumper wire and resistors, then solder the IC socket. If you are good at soldering, then you can bypass the IC socket and solder the PICAXE directly to the PCB. However, I do not recommend this as it is more difficult to replace a damaged IC if it is soldered to the PCB.

Watch the orientation of the IC socket. Although it does not matter electrically, the proper socket orientation keys you to the proper orientation of the PICAXE when you are ready to pop it into its socket. Next, solder the headers and receptacles followed by the LM2940

voltage regulator and 22  $\mu$ F capacitor. Both are sensitive to their orientation, so match them to the illustrations. Double-check your work at this point to verify there are no shorts from the overflow of solder.

## CABLING

Note that there are enlarged holes on the left side of the BalloonSat Mini figures. These are for strain relief of the external cabling. External connections to the PCBs pass through these holes before being soldered to the PCB. This prevents the cables from breaking off over time. I thought I was clever

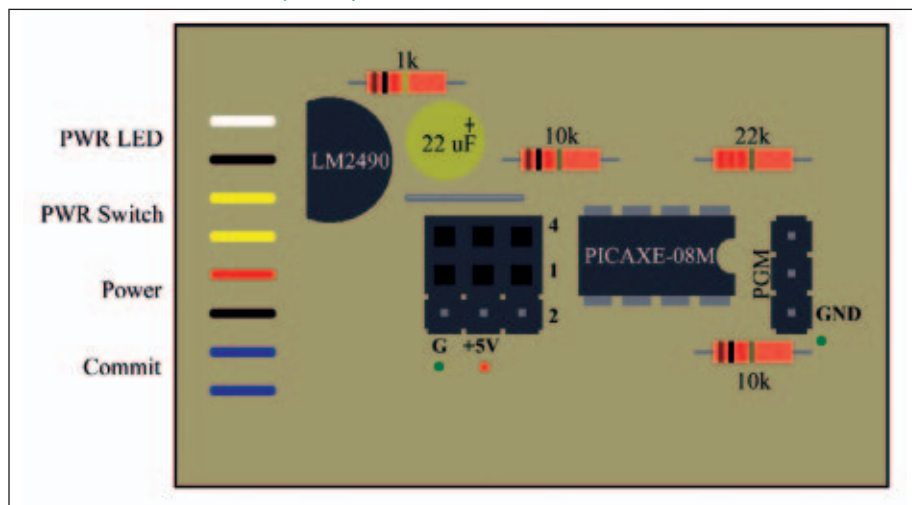
### BALLOONSAT MINI 3 BILL OF MATERIALS

- LM2940 five volt regulator (TO-92 case)
- 22  $\mu$ F radial tantalum electrolytic capacitor (0.1" between leads)
- 1K ohm 5% resistor (1/4 watt)
- 10K ohm 5% resistors (1/4 watt); need two
- 22K ohm 5% resistor (1/4 watt)
- Eight pin DIP socket (0.1" between pins)
- PICAXE-08M
- 1 x 3 male header (0.1" between pins); quantity two
- Subminiature SPST switch
- LED
- 9V battery snap
- 1/8 inch mono jack
- 1/8 inch mono jack receptacle
- Stranded wire (#24 AWG is good)

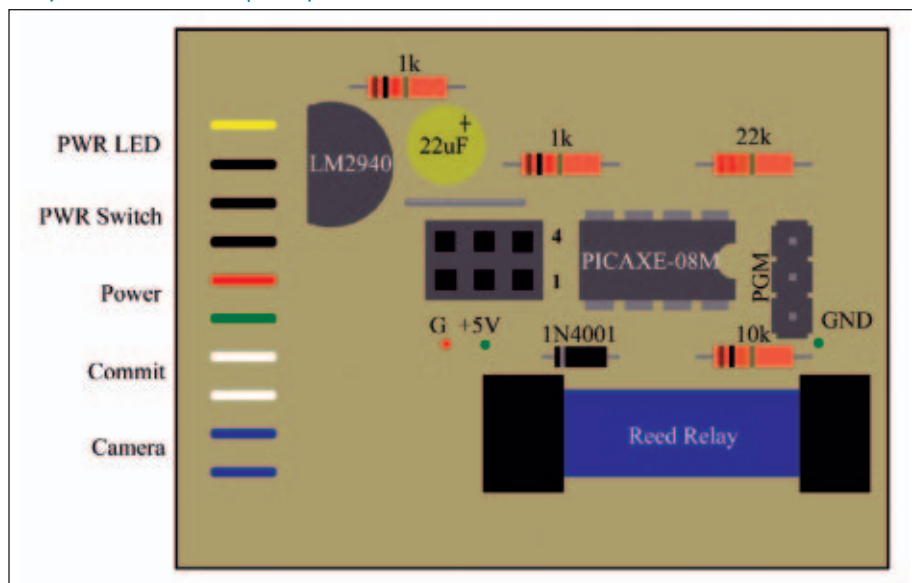
### BALLOONSAT MINI 2 BILL OF MATERIALS

- LM2940 five volt regulator (TO-92 case)
- 22  $\mu$ F radial tantalum electrolytic capacitor (0.1" between leads)
- 1K ohm 5% resistor (1/4 watt)
- 10K ohm 5% resistors (1/4 watt); need two
- 22K ohm 5% resistor (1/4 watt)
- Eighth-pin DIP socket (300 mils wide)
- 3 x 3 female receptacle (0.1" between pins)
- PICAXE-08M
- Mini reed relay
- 1 x 3 male header (0.1" between pins)
- Subminiature SPST switch
- LED
- 9V battery snap
- 1/8 inch mono jack
- 1/8 inch mono jack receptacle
- Stranded wire (#24 AWG is good)

■ Parts placement for the BalloonSat Mini 3. The PICAXE, 22  $\mu$ F capacitor, and LM2940 are the only components that are sensitive to orientation.



■ Parts placement for the BalloonSat Mini 2. Like the BalloonSat Mini 3, only the PICAXE, 22  $\mu$ F capacitor, and LM2940 are sensitive to orientation.



developing this system, but have recently discovered it is used with other PCBs.

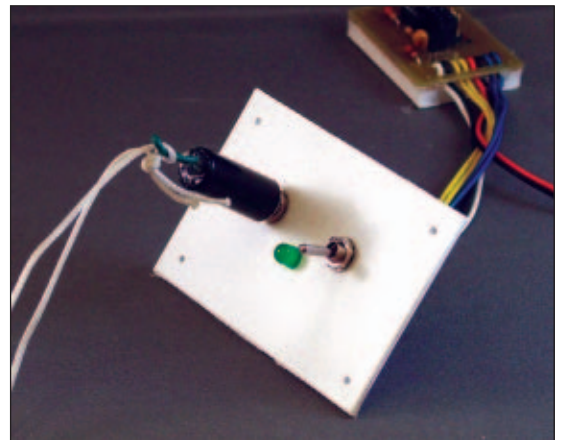
Both Minis use a nine-volt battery snap, so pass the stripped ends of the snap through their strain relief holes and then solder the end of each wire to the PCB. Just watch the polarity of the battery snap when you solder it (the diagram of parts placement is color coded, so you can't mix the wires).

The three remaining wire pairs in the BalloonSat Minis are for the Power Indicator LED, On/Off Switch, and the Commit Pin. Since BalloonSats are usually small in size, the cables can be kept short. Cutting the wires six to eight inches long ought to be good enough. Strip one end of each wire, pass it through its appropriate strain hole, and then solder it to the PCB. I like to color code my wires for the LED so it is easy to identify the correct ones when it comes time to solder the LED to the wires.

After soldering the six wires to the PCB, strip their free ends in preparation for the LED, sub-mini toggle switch, and 1/8 inch phono jack receptacle. The LED cable is stripped back 1/2 inch, twisted tight, and well tinned. Slide thin heat shrink over the tinned leads once the solder has cooled and push them close to the PCB (or else they could prematurely shrink when you attach the LED). Cut back the leads of the LED to 1/2 inch and tin them. Double-check your polarity, then place the proper LED lead flush against the first wire. Heat the LED lead and the wire with a well tinned soldering iron and the two will fuse together. Repeat this for the second lead. Then, slide the heat shrink over the soldered connection and shrink it. The connection will be plenty strong.

The solder tabs of the toggle switch and phono jack have holes to pass the wires through. So, strip an adequate length of insulation from the four remaining wires (one inch of

■ A completed panel for the power switch, indicator LED, and commit receptacle. Notice that the commit pin is made from a 1/8 inch phono jack.



insulation is about right). The heat shrink for the toggle switch and phono jack receptacle is larger than it is for the LED and needs to be test-fitted before you cut it. As you did for the LED, slide the cut heat shrink up against the PCB so it cannot prematurely shrink. Now pass two-thirds of a bare wire through one hole in a solder tab in the phono jack receptacle and twist the wire tight around itself. Solder the twisted wire with just enough solder to lightly coat the twisted wires. Verify no blob of solder is bridging the gap between the solder tabs, then slide the heat shrink over the connection and heat. Repeat this for the remaining three wires. The BalloonSat Mini 2 has an additional cable for the camera. I strongly recommend the end of this cable be terminated in a connector rather than permanently attached to a camera. If the camera is permanently attached, then eventually the cable between the Mini 2 and camera will break from the weight of the camera. I use either a small Dean's connector or a male header. The termination that you use will depend on how you modify your camera. However, I recommend picking a single type of connector and sticking with it.

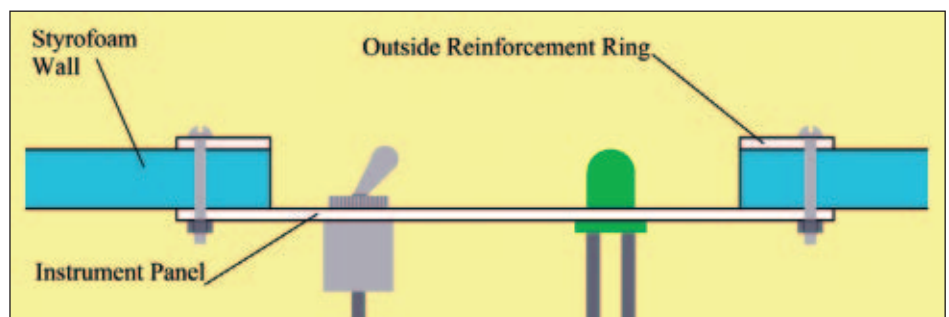
## TESTING AND PAINTING

At this point, you have a complete BalloonSat Mini. However, before snapping in the PICAXE-08M,

take a moment to check your soldering for unintentional shorts (do we ever have intentional shorts?). Make sure solder did not overflow its pad and that no cut leads are sticking to the bottom of the PCB. After a visual check, get out a multimeter and check for continuity between power and ground in the battery snap. Be sure to check with the power switch both turned off and on. If no short is detected, then attach the nine volt battery to the Mini and flip the power switch. You will see the LED light up, indicating power. Now, set your multimeter to measure voltage.

Between pins 1 and 8 of the PICAXE you should measure five volts – give or take 5% – or between 4.75 and 5.25 volts. Then, check the voltage of the I/O ports. To do this, stick cut resistor leads into a +5V and a ground hole of the receptacle to make it accessible to the multimeter. Again, you should measure within 5% of five volts in the receptacle. Of course, if the battery catches fire and sparks fly out of the PCB, disconnect power and look for a short.

Turn off the power before you snap the PICAXE-08M into its socket. A PICAXE-08 will work in the Mini,



■ A side view of the BalloonSat airframe sandwiched between the instrument panel (seen with a switch and LED) and the reinforcement ring.



but use the M model for its additional memory. Now you can apply power and try programming your Mini. Note that the color diagram of the parts layout is marked with a GND on the ground pin of the PICAXE programmer. If you plug the programming cable in backwards, the PICAXE will not program.

The simplest programming test is to write the command DEBUG and download it. The DEBUG command tests that the PICAXE is good and that two-way communication is possible. The result is that you will see the progress of the download and then the debug window open. There will be one debug statement and the values of the memory displayed (which will be all zeros).

After testing the connections on the PCB, mark your Mini PCB with its power and ground indicators. Place a green dot on the PCB next to the ground row of the receptacles and headers (don't forget the programming header). Place a red dot next to

the +5V row of the receptacles and header. Look at the color parts placement diagram for an example.

## BOTTOM SEALING

To protect the Mini from loose objects inside the BalloonSat, cover the bottom of the PCB in a layer of Foamcore, the material used to mount posters. It consists of a thin sheet of Styrofoam backed with paper. The material is easily cut with a sharp X-acto knife. Carve small pockets in the Foamcore where the strain relief wires exit the PCB. Use hot glue to attach the Foamcore to the underside of the PCB and fill the remaining gaps along the edges with additional hot glue.

## PANEL

Now all that remains is managing the LED, power switch, and commit receptacle. I make an instrument panel to do this from a two inch by three inch sheet of 40 mil thick polystyrene. I like the stuff because it

is easy to cut and can be drilled by spinning the tip of the X-acto blade. Make the hole for the switch and phono jack receptacle large enough to mount them. They lock into place with nuts, so don't worry if their hole is a little too large. Make the hole for the LED just smaller than the diameter of the LED so it fits tightly. However, if the hole for the LED is just a little too large, you can use a bit of hot glue to hold the LED in place.

The commit pin is a 1/8 inch phono jack. The jack's tip and base is shorted together internal to the jack housing. That way, when the jack is inserted into the mono jack receptacle, the PICAXE-08M's commit pin (which is pulled high) is shorted to ground. Unscrew the jack housing and solder a doubled-over wire across the tip and base connections. Use a 6" length of wire to do this so when the wire is doubled over, it extends outside the housing. Squirt a little hot glue around the soldered connection of the jack, but be careful not to use so

## PROGRAMMING THE BALLOONSAT MINI

The symbolic code for a BalloonSat Mini looks like this:

### Begin Code:

If the commit pin has been pulled, then download data.

### Commit Pin:

Wait for commit pin to be pulled.

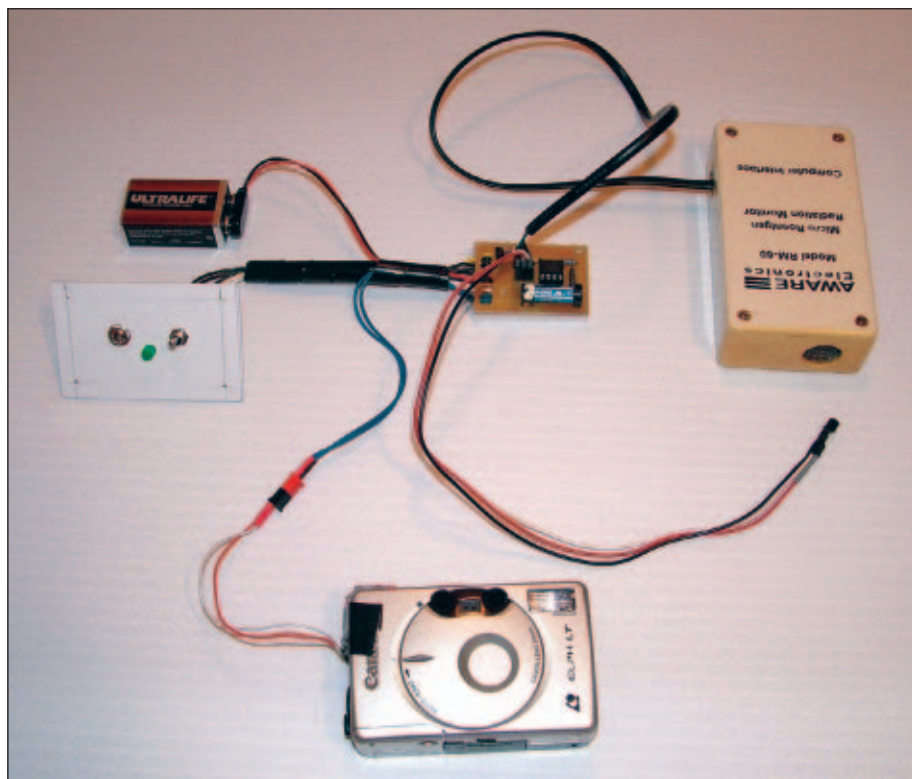
### Flight Code:

Start at memory location 0.  
Digitize analog value(s).  
Write values into memory.  
Increment memory address.  
Record an image.  
Pause.  
Repeat until memory is filled.  
Go to the end of the program.

### Download Data:

Start at memory location 0.  
Step through memory addresses, reading value stored in each location.  
Transmit value to terminal program.  
Repeat until end of memory is reached.

■ This BalloonSat Mini 2 is ready to rock and roll. It will record the air temperature and cosmic ray flux during a mission while also taking pictures from near space. To keep the cables between the instrument panel and BalloonSat Mini manageable, you might try using some spiral wrap as I did.



much glue that the housing cannot be screwed back on. Pass the folded end of the shorting wire through the back opening of the jack housing and screw it back onto the jack. Finish the commit pin by squirting more hot glue through the opening in the back of the housing to create a solid jack. I like to tie a red ribbon to the wire loop protruding from the commit pin so I won't forget to pull it before launching the BalloonSat.

You'll notice there are four small holes in the corners of my instrument panel. I use them to mount the instrument panel to the BalloonSat airframe with 2-56 bolts. The instrument panel mounts to the inside of the airframe and there is a rectangular reinforcement ring on the outside. This ring is the same size as the instrument panel, but it has a rectangular opening with a 1/2 inch border. To mount the instrument panel to the airframe, cut a rectangular hole measuring one inch by two inches in the airframe. The #2 bolts

sandwich the Styrofoam airframe between the instrument panel and rectangular reinforcement ring as illustrated here.

You'll find sample PICAXE code on the *Nuts & Volts* website ([www.nutsvolts.com](http://www.nutsvolts.com)) along with a negative mask of the PCBs of both BalloonSat Minis, if you'd like to make one for yourself.

## NOT QUITE FINISHED

Well, that does it for this month. Next time, I will describe a couple of BalloonSat Mini experiments I have developed along with the next higher level of BalloonSat flight computer. If you would like to order a Mini, please contact me. NearSys LLC is preparing to sell kits of its near space avionics. Kits of every near space flight computer and experiment will eventually be available, but for now, a slightly simpler and more compact version of the BalloonSat Mini is ready. The kit contains a professionally

manufactured PCB with top silkscreen and solder mask along with all the necessary electronic components. The price for the BalloonSat Mini Compact is approx. \$19.50 and the BalloonSat Mini Compact Plus (with camera relay) is approx. \$22.50 (for exact prices check the NearSys website at [www.nearsys.com](http://www.nearsys.com)). There is a \$6 shipping and handling fee for orders in the US. Be aware that large orders may require a different shipping fee. Contact [nearsys@gmail.com](mailto:nearsys@gmail.com) for delivery times and availability. Pictures and assembly directions of each NearSys PCB kit will be available on the NearSys website as they are developed. Along with the NearSys PCB kits, a BalloonSat book is in the works.

Onwards and Upwards,  
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**NOTE:** All PCB patterns and files are available on the *Nuts & Volts* website at [www.nutsvolts.com](http://www.nutsvolts.com).



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# GETTING STARTED WITH PICs

## THE LATEST IN PROGRAMMING MICROCONTROLLERS

■ BY CHUCK HELLEBUYCK

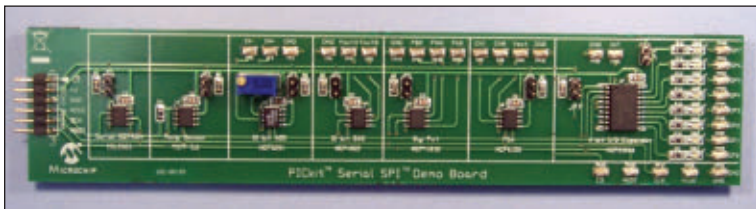
## SPI COMMUNICATION

**WE WERE "LUCKY" ENOUGH TO GET ANOTHER TWO INCHES OF SNOW** here in Michigan, so its been easy to stay trapped inside at my computer cranking out another project to help you get started programming with Microchip PICs. In my January column, I described the I<sup>2</sup>C form of serial communication. This month, I am covering its cousin — the Serial Peripheral Interface or SPI communication.

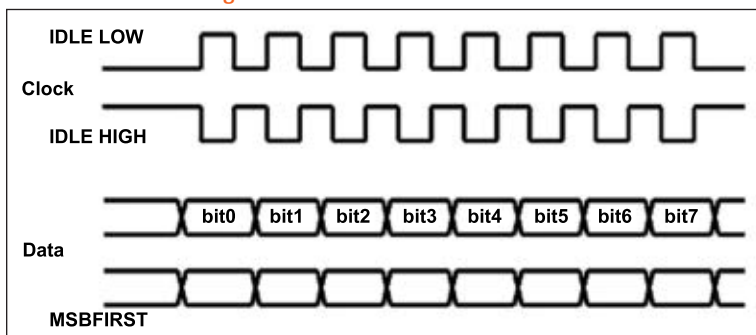
**W**e were "lucky" enough to get another two inches of snow here in Michigan, so its been easy to stay trapped inside at my computer cranking out another project to help you get started programming with Microchip PICs. In my January column, I described the I<sup>2</sup>C form of serial communication. This month, I am covering its cousin — the Serial Peripheral Interface or SPI communication. I'll perform the same function and

communicate with a serial EEPROM as in my January column, but this could easily be a temperature sensor, an external Analog-to-Digital Converter (ADC), a Digital-to-Analog Converter (DAC), digital potentiometer, programmable gate array, or an eight-bit I/O expander. In fact, all of these items are included on the Serial SPI Demo Board you can get from microchipDIRECT ([www.microchipdirect.com](http://www.microchipdirect.com); see Figure 1).

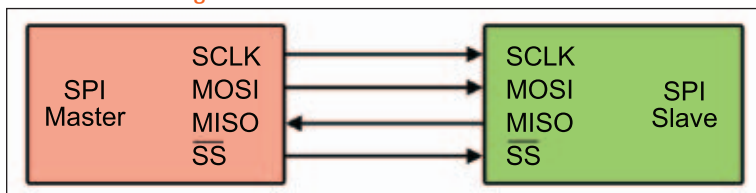
■ FIGURE 1. Microchip Technology's PICKit Serial SPI Demo Board.



■ FIGURE 2. SPI Signal Formats.



■ FIGURE 3. Single Slave.



Many chips offer SPI capability, including PIC microcontrollers (MCUs). The SPI bus operates in a master-slave arrangement. The master supplies the clock and data to the slave. The master can also have a third line for receiving and then a fourth line for controlling which slave to talk to on the bus. This is why the SPI bus is sometimes referred to as a "four-wire" serial bus. The SPI bus is not really a true standard with a platform agreed to by an international committee like I<sup>2</sup>C. This leaves the SPI bus open to interpretation by the maker of the slave device. It is critical that you read through the datasheet for the slave device you are using. Some may want the data to clock in on the rising edge of the clock signal while others may want to clock in on the falling edge of the clock signal. The thing you'll notice most — if you've worked with digital chips for years — is that SPI looks a lot like the old-fashioned method of clocking data into a shift register.

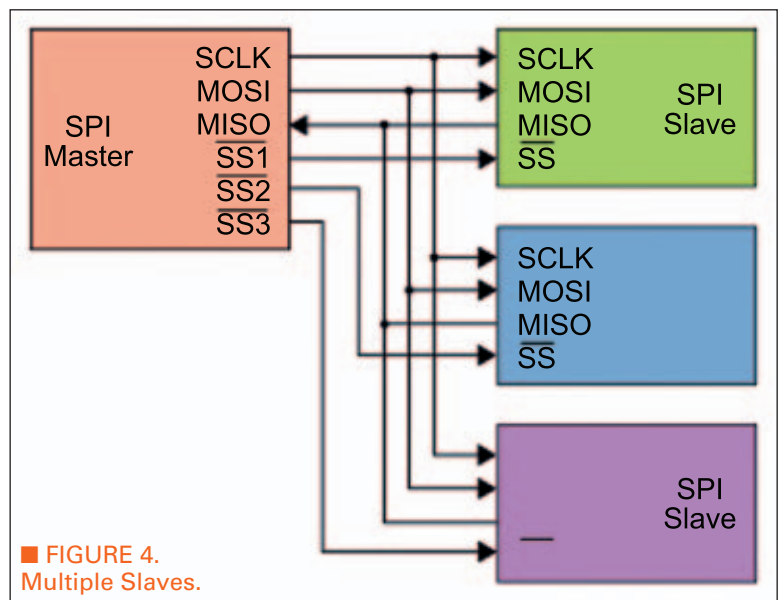
## SPI BASICS

The master SPI signal is essentially a clock and data output signal, also called the Master Output Slave Input (MOSI) signal. The clock can idle in a low state or a high state. Both are shown in Figure 2. The data output can be sent the Least Significant Bit (LSB) first or the Most Significant Bit (MSB) first (also shown in Figure 2). The data is shifted in on the



rising or falling edge of the clock, per the circuitry inside the slave device. A second data signal is used as the master input signal, also called the Master Input Slave Output (MISO). As the master clocks the data out, it also clocks the data into its own buffer. Therefore, the slave must have its data ready to send when the master starts clocking. The only way the slave can determine that the master is going to start sending is to monitor its Chip Select (CS) or slave select (SS) line to see whether the master has pulled it low. When your setup has only one slave, it is still a good practice to use the CS line.

The CS or SS line is the key to having more slaves connected to a single master. The master will pull the CS line low for the slave it wants to talk to and, when the communication is done, the master pulls that CS high and then pulls the CS line low of the next slave to talk to. This allows multiple slaves to share the same set of clock and data lines. Figure 3 shows a single slave and Figure 4 shows multiple slaves.



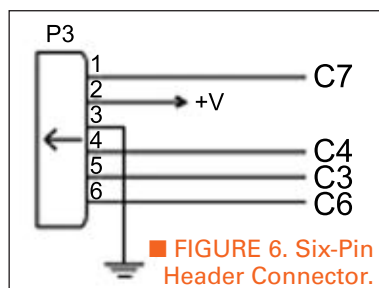
■ FIGURE 4. Multiple Slaves.

## USING SPI WITH THE PICBASIC PRO COMPILER

The microEngineering Labs PICBASIC PRO compiler simplifies SPI down to a single command. Many PIC MCUs have a hardware SPI peripheral built in, so the communication can happen in the background while the software is doing something else. The PICBASIC PRO method uses a "bit banging" or "firmware" implementation of SPI. This prevents the software from multitasking during SPI communication. The firmware method allows you to use SPI on any PIC MCU. The small eight-pin PIC12F683 MCU doesn't have a SPI peripheral, so the PICBASIC PRO method makes sending SPI from this small chip very easy. However, I went the other direction and used a larger chip than the normal 20 pin PIC16F690 that I have used in previous articles. In this month's project, I use a 28 pin PIC16F870. The reason for this has less to do with the chip than the development board.

## HARDWARE SETUP

The development board I used is shown in Figure 5. It is a PICKit 2 board that you can purchase separately. You get one fully populated board with a PIC16F886 MCU, and then two blank boards. The PICBASIC PRO sample version doesn't support the PIC16F886, but it does support the PIC16F87X parts. The



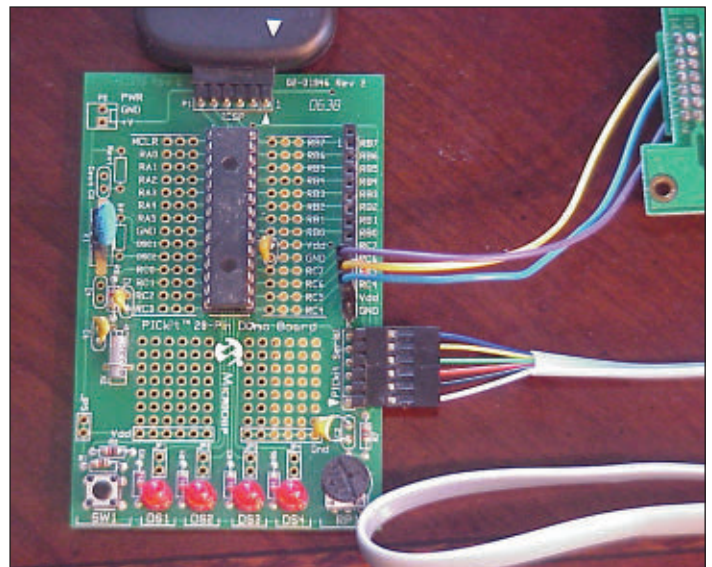
■ FIGURE 6. Six-Pin Header Connector.

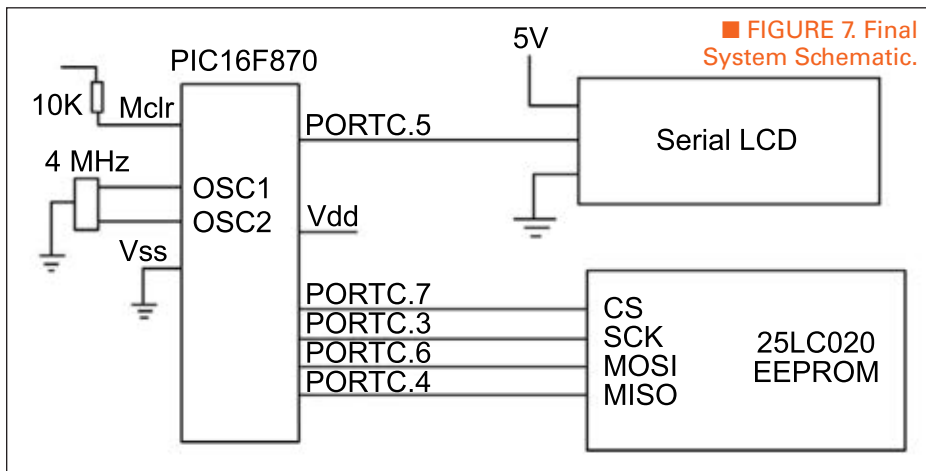
PIC16F870 is a 28 pin part in this family that works with this board.

The main reason I selected this board over the PIC16F690 is the six pin header on the side labeled "PICKit Serial." This six pin header is designed for serial communication to Microchip's PICKit Serial Analyzer tool. The tool also works as a great connection header to the PICKit Serial SPI Demo Board shown in Figure 1. With a simple six pin cable that I had in my pile of lab extras, I could easily connect the two boards together. The microcontroller connections for this header come from the PORTC pins of the 28 pin socket, per the schematic in Figure 6.

The PIC16F870 doesn't have an internal oscillator option, but the development board has the circuitry included for an external oscillator. I added a three pin socket and then plugged in a three pin resonator with capacitors built in. I ran the project at 4 MHz, which is the

■ FIGURE 5. PICKit 2 28-pin Development Board.





■ FIGURE 7. Final System Schematic.

## SOFTWARE

I wrote the software in blocks to make it easier to explain the operation. Combine all the blocks together for the complete software routine. I start off with a simple description of the operation and then set up the port settings. The labels SI and SO are from the EEPROM perspective. The LCD is on PORTC.5. I use a VAR or variable directive to establish these labels, even though it may seem like they could be constants. The labels can't be constants though, because the value

default speed for the PICBASIC PRO compiler. The final schematic is shown in Figure 7.

The demonstration program I wrote initially writes 16 bytes of data to the EEPROM and then reads each byte back one at a time. This is done over and over again in a continuous loop, with each value displayed on an LCD module. Because the sample version of the PICBASIC PRO compiler only supports 31 commands, I needed a simple way to display the data. The problem I found driving a parallel LCD module was that it took too many set-up lines and pushed me beyond 31 commands.

My second choice was a serial LCD module. With a single SEROUT command and three connections — 5V, ground, and signal — I could easily display the data read from the EEPROM. I used a serial LCD module from microEngineering Labs connected to a 2 x 40 LCD. The LCD is connected to the MCU's C5 pin through the expansion header on the side of the development board, making this an easy connection. The expansion header has 5V and ground connections, as well. The final setup is shown in Figure 8. The PICkit 2 supplied enough current to power the whole circuit through the USB connection. No jumper wires, no soldering, and no separate breadboard. You can't get much easier than that.

can contain a zero or one value, thereby requiring a variable definition. As a final step, I preset the input and output states of the pins by writing directly to the TRISC register. A one makes the pin an input and a zero makes the pin an output. The most significant bit is to the left.

```
' Program to read and write to SPI EEPROM
' 25LC020 on PICkit Serial SPI Demo Board
' using PIC16F870.
' Write to the first 16 locations
' of 25LC020 serial EEPROM.
' Then Read first 16 locations back
' and send to LCD repeatedly.
```

```
' *** Port Settings ***
CS   var   PORTC.7   ' Chip select
SCK  var   PORTC.3   ' Clock pin
SI   var   PORTC.6   ' MOSI pin
SO   var   PORTC.4   ' MISO pin
LCX  var   PORTC.5   ' LCD

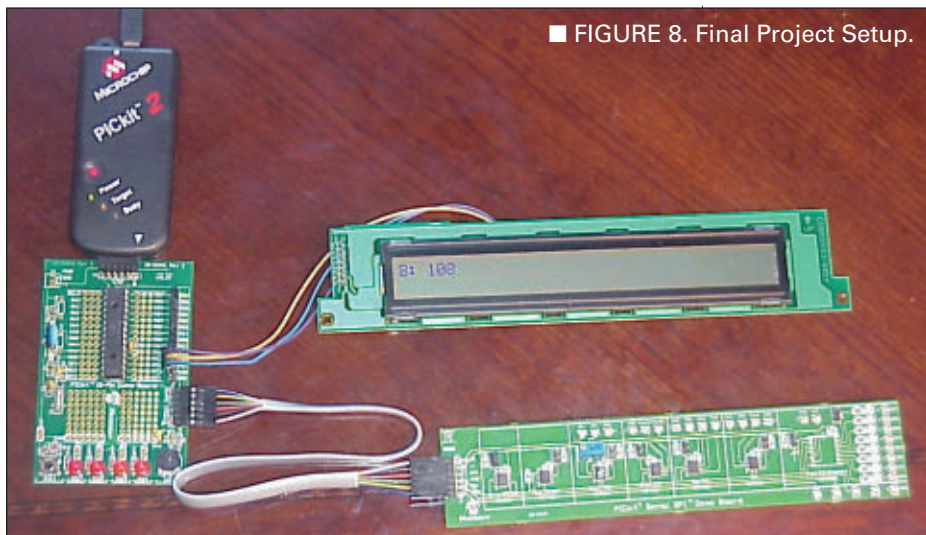
' C4 input, C7-C5, C3-C0 outputs TRISC =
%00010000
```

The next section creates two byte variables that I will use throughout the program. One is the "addr" variable that contains the address of the data to be read or written.

The other is a general-purpose "B0" variable that I use to hold the data being written to or read from the EEPROM. The 25LC020 EEPROM uses eight bit communication. Check the datasheet of the EEPROM you use in your SPI communications because some require a 16-bit address.

```
*** Variable Setup ***
addr var byte          '
Address
B0   var byte          '
Data
```

The "main" label marks the FOR-NEXT routine that loads the initial data into the EEPROM. The addr variable is used as a counter variable, and also as



■ FIGURE 8. Final Project Setup.



the address of the location where we will write the data to inside the EEPROM. The data will be the address value plus 100, so the first location address zero will contain the value 100. Address one will contain the value 101. This continues for all 16 locations (0-15). The loop uses a subroutine called "eewrite" to actually write the data. I'll cover this a little later. The pause 10 delay is a 10 millisecond delay between write operations that is required by the EEPROM so it can finish what it's doing.

```

**** Load Data in EEPROM ****
main:  For addr = 0 To 15      ' Loop 16 times
        B0 = addr + 100        ' Data for SEEPROM
        Gosub eewrite          ' Write to SEEPROM
        Pause 10               ' Delay 10ms
        Next addr

```

The "loop" label marks the continuous-read loop of the EEPROM data and the display of that data on the serial LCD. The loop uses a FOR-NEXT loop again, with the "addr" variable as the counter and address locator. Another subroutine to read the EEPROM is then called. The SEROUT command line sends a command \$FE, \$1 to position the data at the first line, first location of the LCD screen. Then, the ASCII representation of the address is displayed, followed by a colon and space; and then the ASCII representation of the data is then read from the EEPROM. The # symbol converts the number into its ASCII characters (i.e., 105 is sent as '1','0','5'). The value "6" in the SEROUT command line represents a non-inverted 9600 baud rate. This was the communication speed the LCD required. The pause 1000 creates a one second pause, so you can see the data on the LCD; then the next value is retrieved. After all 16 bytes of data are captured and displayed, the whole process starts again. Figure 9 shows one of the results displayed on the serial LCD.

```

' Continuous Loop to Read and Display Data
loop:  For addr = 0 To 15      ' Loop 16 times
        Gosub eeread          ' Read from EEPROM
' Display data read from EEPROM on LCD
        SEROUT LCD,6,[$FE,$1,#addr," : ",#B0]
        Pause 1000
        Next addr

        Goto loop

```

The subroutines make up the heart of the code. The SHIFTOUT command is used to send the command value \$03 to the EEPROM. This indicates that the master wants to read a value from the EEPROM at a specific address. The second byte contains the address in the "addr" variable. Before this will work, though, the chip-select line must be brought low by setting the CS variable to zero. The SHIFTOUT command line designates the pin connections, and then the value "1" is a PICBASIC PRO value that indicates the most significant bit (MSB) will be sent first with clock idle in the low state.

The data is read back using a SHIFTIN

command and stored in the variable B0. The "0" in the command line is the PICBASIC PRO code to command the data to be sent MSB first and read the data, before sending the next clock. The clock will also idle low. The CS line is set high, to end the operation and then the RETURN command sends the control back to the program section that called this subroutine.

```

' Subr. to read data from addr in serial EEPROM
eeread:
        CS = 0                ' Enable serial EEPROM
        ' Send read command and address
        Shiftout SI, SCK, 1, [$03, addr]
        Shiftin SO, SCK, 0, [B0] ' Read data
        CS = 1                ' Disable
        Return

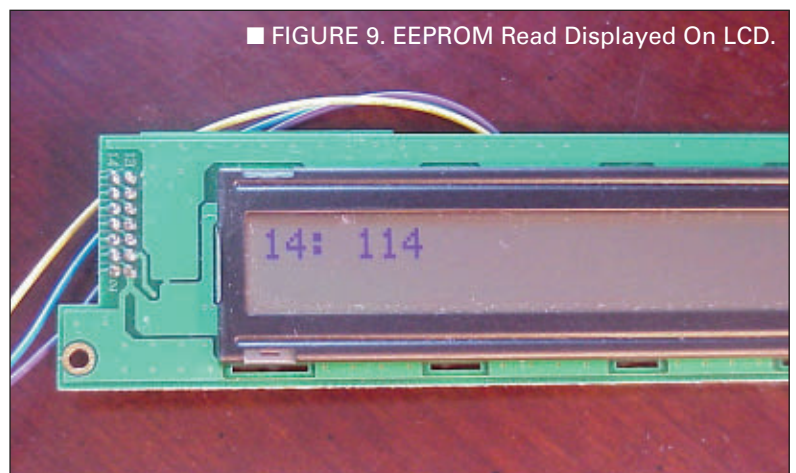
```

The second subroutine is the write routine that uses two SHIFTOUT commands. First, the CS line is pulled low to enable the EEPROM for communication. Then, the command code \$06 is sent to the EEPROM. This tells the EEPROM to allow the data to be modified, also known as the "write enable" mode. The CS line is brought high to end that command and allow the EEPROM to enter the write-enable mode. I added a small delay and then pulled the CS line low again, to send the data byte. The SHIFTOUT command sends the \$02 command to indicate write mode, and then the address and byte data values to store. The value "1" indicates MSB. The CS line is brought high again to end the communication; the EEPROM then writes the value to the memory location. Location 14 has the value 114 stored in it, and Figure 9 shows that value displayed. A RETURN command gives control back to the code that called the subroutine.

```

' Subr. to write data at addr in serial EEPROM
eewrite:
        CS = 0                ' Enable serial EEPROM
        ' Send write enable command
        Shiftout SI, SCK, 1, [$06]
        CS = 1                ' Disable to exec command
        CS = 0                ' Enable
        ' Send address and data
        Shiftout SI, SCK, 1, [$02, addr, B0]
        CS = 1                ' Disable
        Return

```







As a final step, I added an END command to mark the end of the program. This is always a safe way to complete a PICBASIC PRO command.

```
' *** Mark End of Program ***  
End
```

## CONCLUSION

The SPI Demo Board has several different SPI chips to talk to. The SHIFTIN/SHIFTOUT commands can be used to talk to any of them. SPI communication is really easy to understand, once you get the basics down. The problem is that it takes up more I/O with all the extra CS pins for each SPI chip you use. This is an advantage to I<sup>2</sup>C that I covered in my previous column. SPI is typically faster than I<sup>2</sup>C, though, so it can sometimes offer an advantage. However, if the EEPROM takes 10 milliseconds to complete a write operation, that becomes the limiting time factor.

I like to think about next steps for all my projects so the reader can take what I taught them and prove to themselves that they understand it by going further with the same hardware. This setup lends itself perfectly to that concept. The SPI demo board has multiple chips on which to experiment. Each chip requires you to read the datasheet for any command codes required, but these

are all free to download from [www.microchip.com](http://www.microchip.com). The CS line on the demo board was designed for one-chip communication only, with jumpers to select the chip. Communicating with multiple SPI parts requires you to create jumper wires from the MCU's extra CS lines to the CS connections on the demo board. This could be an interesting project — I just didn't have time to try it.

Another source of information regarding serial EEPROMs is the Microchip "Recommended Usage" application note for SPI Serial EEPROMs (AN1040) and the datasheet for the 25LC020. Both are also available for download at [www.microchip.com](http://www.microchip.com).

Let me hear your feedback on this column or previous columns. I've gotten some email from people who are still working on projects from the 2006 articles. If you missed these, they're compiled together in a book entitled *Getting Started with PICs* (2006) that you can purchase from the *Nuts & Volts* webstore (<http://store.nutsvolts.com>). Just shoot me an email at [chuck@elproducts.com](mailto:chuck@elproducts.com), and type *Nuts & Volts* in the subject line so it doesn't get lost among the numerous junk emails I receive. See you next time! **NV**

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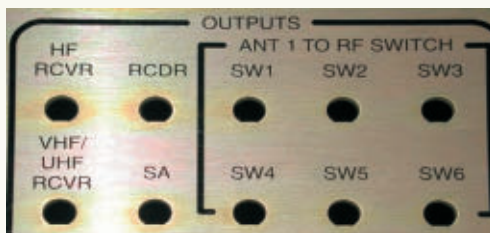
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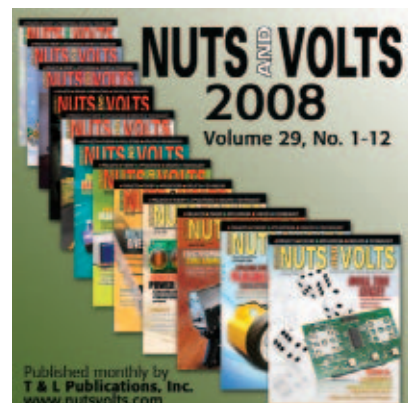
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PIC Microcontrollers are present in almost every new electronic application that is released from garage door openers to the iPhone. With the proliferation of this product more and more engineers and engineers-to-be (students) need to understand how to design, develop, and build with them. Martin Bates, best-selling author, has provided a step-by-step guide to programming these microcontrollers (MCUs) with the C programming language.

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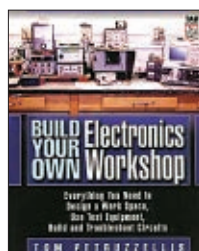


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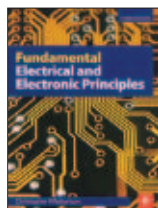


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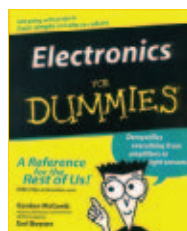
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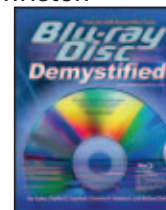
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by Jim Taylor, Michael Zink, Charles Crawford, Christen Armbrust

Pub Date:

November 10, 2008

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### Beginner's Guide to Embedded C Programming Combo by Chuck Hellebuyck



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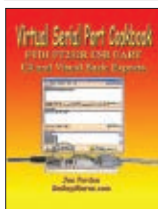
The C language has been covered in many books but none as dedicated to the embedded microcontroller beginner.

Through his down-to-earth style of writing, Chuck Hellebuyck delivers a step-by-step introduction to learning how to

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The PICkit 2 Starter Package is used for all the projects in the book and includes the HI-TECH PICC-Lite Compiler and a PIC16F690.

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As talked about in the *Nuts & Volts* June issue, "Long Live The Serial Port"



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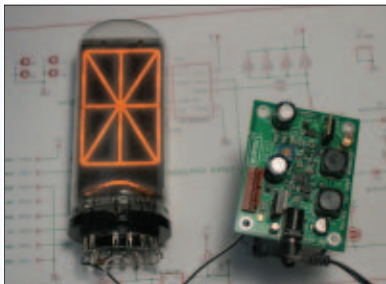
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**For more information, please check out your April 2008 issue or go to our website @ [www.nutsvolts.com](http://www.nutsvolts.com)**

For more info on soldering SMT components, see the video "Getting Started with Surface Mount Components" on the product detail page in our webstore.

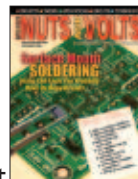
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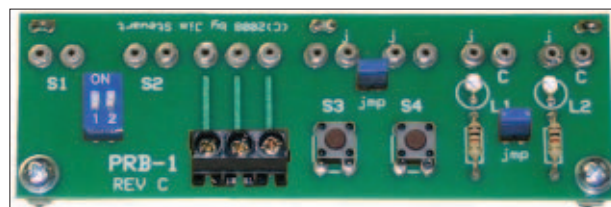


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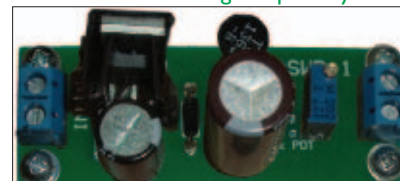
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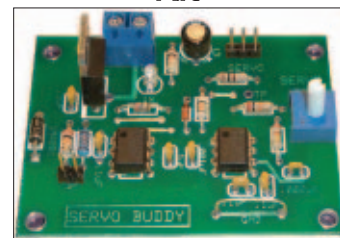
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Publish Date: October 10, 2008

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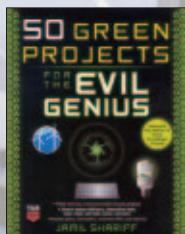
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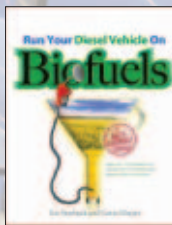
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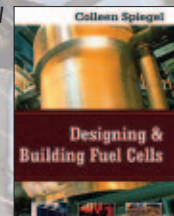
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## Bretthauer Appointed CEO of LPKF Laser & Electronics AG

The Supervisory Board of LPKF Laser & Electronics AG has appointed Dr. Ingo Bretthauer (53) as the new Chief Executive Office of LPKF AG, beginning Feb. 1, 2009. Alongside the current members of the Board of Managing Directors (Bernd Lange, 48 and Kai Bentz, 37), Bretthauer will in particular push ahead the global sales of all LPKF products. Bretthauer has broad experience in sales and marketing of industrial equipment. With a degree in engineering and a PhD in economics, he previously worked seven years in various positions at AEG. He moved from AEG to Deutsche Bahn, where his last position was Chief Marketing Officer at DB Reise & Touristik. He was CEO and sole managing director of Joh. Heinr. Bornemann GmbH in Obernkirchen, Germany from 2001 to 2007.

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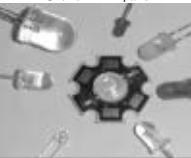
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# TECH



# FORUM

## This is a READER-TO-READER Column.

All questions *AND* answers are submitted by *Nuts & Volts* readers and are intended to promote the exchange of ideas and provide assistance for solving problems of a technical nature. Questions are subject to editing and will be published on a space available basis if deemed suitable by the publisher. Answers are submitted by readers and **NO GUARANTEES WHATSOEVER** are made by the publisher. The implementation of any answer printed in this column may require varying degrees of technical experience and should only be attempted by qualified individuals. Always use common sense and good judgement!

All questions and answers should be sent by email to [forum@nutsvolts.com](mailto:forum@nutsvolts.com). All *diagrams* should be computer generated and sent with your submission as an attachment.

### QUESTIONS

To be considered, all questions should relate to one or more of the following:

- ① Circuit Design
- ② Electronic Theory
- ③ Problem Solving
- ④ Other Similar Topics

■ Be brief but include all pertinent information. If no one knows what you're asking, you won't get any response (and we probably won't print it either).

■ Include your Name, Address, Phone Number, and email. Only your Name, City, and State will be published with the question, but we may need to contact you.

■ No questions will be accepted that offer equipment for sale or equipment wanted to buy.

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### ANSWERS

■ Include in the subject line of your email, the question number that appears directly below the question you are responding to.

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■ Comments regarding answers printed in this column may be printed in the Reader Feedback section if space allows.

## >>> QUESTIONS

### Plasma Speakers

Does anyone have any schematics and info on building a plasma speaker? I have seen [www.instructables.com/id/Build\\_A\\_Plasma\\_Speaker/](http://www.instructables.com/id/Build_A_Plasma_Speaker/), however, some of the details regarding the driver and other info is not stated.

#3091

**Bill Lost**  
via email

### Detecting a Fault on a High-Side OMNIFET

I am designing an H-bridge motor driver using two STMicro L6384 drivers, and four VNV35N07 OMNIFETs. Since the OMNIFETs are internally protected, I hope to avoid using sense resistors for fault detection. Please suggest an elegant way to detect faults on the highside. If a highside VNV35N07 has clamped the gate, what is a good way to detect this and produce a 5V logic level signal referenced to ground? Power supply to the H-bridge will usually be 24 VDC, though it could be anywhere from 6V to 30V.

#3092

**James Smith**  
Ontario, Canada

### Matching Transistor Gains

I am looking for a practical vs. exotic bench setup to determine the gain of some power TO-3 transistors. I'm working with an old piece of equipment that requires matched transistor sets. It was going to be replaced in the near future,

but "near" is beginning to look like "someday." So, for the indefinite future, we need to keep the existing units alive and the dead ones restored.

#3093

**David Bassett**  
Summit, NJ

### ESD Protection

I have designed and built a USB dumb data terminal for Time and Attendance tracking. My problem is that now that the device is in production, static discharge to the device resets the MCU. It's a very simple design using only an LCD, PIC chip, membrane switch (with grounding layer), a plastic enclosure, and a USB cable to connect to the computer. I have a grounding layer on the PCB and the cable's shield and the membrane grounding layer are connected to it. Routing the membrane grounding layer to the cable shield bypassing the PCB ground improves ESD performance, but not completely. What should I be doing?

#3094

**Michael Lange**  
GA

### Voltage Regulators for Bicycle Lights

I have an electric bicycle that runs on 36 VDC and would like to make a circuit that would power the lights and radio on the bike. There are four items all powered by various quantities of AAA batteries.

There is 1@6V, 1@4.5V, and 2@3V. If someone could provide me with a



circuit diagram, I would appreciate it.  
**#3095** **David Luther**  
**Los Angeles, CA**

### Digital Multimeter Input Impedance

I have purchased an inexpensive DMM which appears to work satisfactorily. Is there a method to measure the input impedance of the meter?

**#3096** **Doug Poray**  
**Jackson, NJ**

## >>> ANSWERS

### [#1099 - January 2009] Electronic Simulation Software

*I see simulations of circuits in many articles. I used to have a copy of Electronic Workbench 12 years ago, but found it to be unreliable in switch mode designs. I would like to know what package you recommend for mixed signal and switch mode design simulation that is easy to use and under \$1,000. Also, I have been out of electronics for six years and need a single source for info on SMT packaging.*

**#1** Surprisingly, there are a couple of free circuit simulation software packages available. I like Linear Technology's LT SPICE IV (Switcher CADIII), which is a general SPICE program, but uses a specific algorithm to do switch mode simulation extremely well. It excels at start-up and transient events, and rarely fails to find the operating point or hangs. The program updates frequently and other SPICE models are easily added. Almost all of their products are supported. Also, there is TINA-Ti (Texas Instruments) and National Semiconductor has a web-based solution. The best sources for SMT information are the manufacturers themselves, since most of them have extensive tutorials and PDF files available. Other good sources are the PCB manufacturers and many of them have free layout software. I recommend **expresspcb.com**; they have an excellent, brief (on-line) manual and CAD software to get you going quickly. Other good sources right now are the solder manufacturers, parts, and equipment makers, due

to RoHS (Restriction of Hazardous Substances).

**Walter Heissenberger**  
**Hancock, NH**

**#2** You probably sent this SPICE question in a few days before the December 2008 issue of *Nuts & Volts* was published. The most inexpensive SPICE for the MS Windows OS is described in "A Touch of SPICE" by Peter Stonard in the December 2008 and January 2009 issues. This superb introduction to LT SPICE (Linear Technology SPICE) will get you started on a package with a schematic capture front end. LT SPICE is probably the best answer.

If you have a rich employer to buy Electronic Workbench, the schematic capture is much improved. Back when you were using EW, I used Penzar TopSPICE to good effect when it was half today's \$500 price. If your employer provides OrCAD schematic capture, consider PSPICE. Most of the published SPICE netlists are based on PSPICE. There is a free student version of OrCAD/PSPICE.

I got a lot of mileage out of the PSPICE student edition before it had schematic capture in the early 80s because my "fortune 100" employer wouldn't buy it. I actually learned SPICE from Intusoft newsletters and books. They sell IsSPICE. They are very good at providing models of exotic devices.

These days, I am Linux OS based using Xcircuit schematic capture and a patched version of Berkeley SPICE 3f5. I don't recommend this approach for casual users. See Kuphaldt, "Lessons in Electric Circuits" AC, Chapter 6 on the web for examples.

**Dennis Crunkilton**  
**Abilene, TX**

### [#12086 - December 2008] Power Tool Batteries

*Does anyone have information on how to recell/rebuild power tool batteries? Procedures and suppliers of equipment needed to do it properly?*

I have rebuilt numerous power-tool batteries, generally upgrading them as far as capacity (ma/hrs) and

reliability as I did. I have discovered that about 90% of all common tool batteries are made up of sub C size NiCds or NiMh cells. A few older ones were actually full size D cells (not the Eveready, etc., D cells with a 1/3 D tucked in one end that they sold as rechargeables for home use to replace dry cells). Those D cells were very powerful and heavy. There is also a smattering of AA, AAA, AAAA, and "coin cell" stacks out there now. Then there are lead-acid, lithiums, and nickle-iron Edison cells, and even some alkalines.

The most important thing is that the cells you rebuild with need to be as identical as possible to each other in capacity, internal resistance and charge and discharge rates, as your battery pack can only perform as well as its weakest link.

Another consideration is operating temperature (there are high temp versions) and the temperature tolerance of the insulation around the cells — some of the plastics used on China imports melt and short the cells together — a common failure in "liquidation store," weak, low priced drills and saws. I have found the blue plastic thin insulation on available high capacity cells and the old standby "cardboard" or pasteboard paper-like insulation to perform well. The non-oil or non-plastic soaked pasteboard insulation's only flaw is that continual repeated exposure to moisture and/or salt water can cause a high resistance short between cells due to either salt or mineral build-up and residual moisture or iron oxide (rust) from the cell's outer case permeating the material. Use the plastic or soaked "paper" insulated cells for tools, RC toys, etc., used in rain or underwater cameras, for example. I have soaked paper ones in varnish or polyurethane when desperate, and have also seen wax used.

I now go on the Internet Googling NiCds or NiMH or batteries, etc., to find good ones at a good price — 2,250 ma/hr is easy to come up with and close to that in sub C NiCds, but I don't remember the site. They were cheaper than the 1,250 ma/hr ones. Over 5,000 ma/hr units have been located. There appears to be a

premature aging/loss of capacity problem when overcharging or stored unused over a month with some of the higher Ma/Hr NiMH ones.

To test the response of the cells, I build chargers to charge each 1.2V cell individually, then discharge it into an identical load (light bulb, resistor, etc. — a bulb gives you a visual observation too) and repeat the procedure a dozen times, running the cells down to a given voltage. Normally, a charge rate of amperes over a given time period is given by the supplier and I follow that. I discharge all cells over the same time period on the last discharge and then check their voltage to see what they've discharged to, which provides me with a base discharged voltage. I pick the highest discharged voltage I can find enough cells at to rebuild the battery with. Many commercial rebuilders do not do this and use mismatched cells as a result. NiMH cells have a higher capacity than NiCd's — sometimes double in the larger cells. Do not mix these two types.

Most original battery packs are connected together via flat sheet metal conductors spot-welded to cell cases. Tips and wires are soldered to tabs spot-welded to those areas. In the 1960s, electric toothbrushes appeared with two sub C cells soldered with tin/lead solder, so that's how I rebuilt mine using salvaged cells. A few times I had solder melt when batteries overheated due to a motor shorting out to .5 ohms. Those occurrences disappeared (along with charred pasteboard insulation) with the factory installation of thermal breakers. Re-install those in the same place as the original if you can. Now, I tend to use tin/Cu/selenium solder. In rare instances, I spot weld using either a 50,000 mfd capacitor at 6V or a relay discharging a high voltage (110 VAC or 250 VAC) into a transformer primary for a short burst and use the secondary low (2.5 to 35V) to do the spot-welding using Cu as the metal contacting the weld. Pull that electrode back quickly while holding the metal band tightly to the cell.

I have used such tools as a "Panelspotter" to accomplish this, but

it's not really necessary if you're good at tinning both cell and connecting wire or band, and then heating them together while pressing the connection flat with a tool that solder doesn't stick to — like a popsicle stick. Thick solder joints eat up precious space in the battery shell and may cause a problem closing it up. Thick rubber bands can help bundle cells together for connecting. I generally copy the layout of the original battery.

A small (15, 25, 35 watt) soldering iron will work but I prefer a real chromed brass secondary solder gun like the Weller 8200 (125/150 watt), D-440 (400W), D550 (500W), D-660 (600W), as the higher heat does not have to be applied as long to heat the connection. The longer heat is supplied, the more likely a seal failure or other damage can occur.

Lithium cells can be replaced in the same manner as NiCd's and NiMH when all cells are not cast in the same plastic or physically are not a part of the plastic housing. A similar problem exists with many lead/acid batteries (gel cells) although some are made up of individual 2V usually steel jacketed cells such as Gates "Cyclon" cells (often D size) that can be easily soldered together and are usually supplied spot-welded on the solder tabs.

Many NiCd's and NiMH also have metal bands already spot-welded to them so you can solder to the next cell in your pack's band; bands are available separately. I like to use thin copper strips from old TV chassis ground straps. Bands supplied on cells are usually so long they have to be trimmed on one cell at least. Battery shells are usually screwed together, sometimes with goofy heads on screws like tri-way, torx, Canadian Phillips, and all common ones with a post sticking up in the middle of it. Some cases are welded and need to be split by controlled violence, or cut and reassembled by thermal or solvent welding or welding in plastic to hold nuts, or be drilled for screw supports. All in all, it's really a fun adventure and with some experimentation, a far superior battery can be created!

**Bob Kennet  
Everett, WA**

## Logic Analyzer

*I have a LEADER Model 300 DMM/scope with logic analyzer. I need help/info to build an interface circuit that would allow me to use the eight channel logic analyzer.*

I recommend against building your own probe, because you may encounter insurmountable obstacles due to parts availability. I do recommend, however, to go out on eBay and either find the probe, or find a repairable one. The service manual for the LEADER Model 300 is available at Manuals Plus for about \$40, which is somewhat typical. A logic analyzer probe sells for about \$20-200 on eBay. Consider buying a Tektronix 1230 or 1241 logic analyzer instead, which are much better instruments and can be had for as little as \$30, since labs are shutting down due to the economy. I also like the HP1631D, which is a 50 MHz, two channel scope mated to a logic analyzer and it has the pods (probes) attached. I've seen the HP1631D sell for as little as \$20.

Interestingly, probes tend to be somewhat expensive and harder to get, probably because fewer functional ones have survived.

**Walter Heissenberger  
Hancock, NH**

## [#1098 - January 2009] Humidity Sensor

*I am looking for a small humidity sensor circuit powered by 120V that can trigger a relay based on an adjustable humidity level. My ultimate goal is to wire it into a bathroom fan and have the relay trigger an X10 command via an X-10/Insteon I/O module. The X10 command would turn the fan on or off based on the humidity in the room and the humidity trigger level set. It needs to be small and self-contained (no wall wart).*

Check out **graininger.com** and look for "humidity control" or part number 2E574; 2E574 is an adjustable humidistat that will work with your X10 system or as a stand-alone control using 120 VAC.

**Bob Lindstrom  
Broomfield, CO**





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AP Circuits .....70

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Saelig Company, Inc. ....53

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Electronix Express .....75

Front Panel Express LLC .....52

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Command Productions .....11

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## **EMBEDDED TOOLS**

Mouser Electronics .....9

NetBurner .....7

## **ENCLOSURES**

Integrated Ideas & Tech. ....86

## **KITS & PLANS**

DesignNotes.com, Inc. ....35

Earth Computer Technologies .....35

Electronics 123 .....35

Jaycar Electronics .....33

NetBurner .....7

PAiA .....11

QKITS .....35

Rabbit, A Digi International Brand .....3

Ramsey Electronics, Inc. ....26-27

Solarbotics/HVW .....14

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## **MISC./SURPLUS**

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## **MOTORS**

Jameco .....15

## **PROGRAMMERS**

Electronics 123 .....35

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## **RF TRANSMITTERS/ RECEIVERS**

Linx Technologies .....39

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DLP Design .....10

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Electronic Design Specialists .....14

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Electronix Express .....75

ExpressPCB .....24

Front Panel Express LLC .....52

Fun Gizmos .....35

HobbyLab .....35

Integrated Ideas & Tech. ....86

Jameco .....15

Jaycar Electronics .....33

LeCroy .....5

Lemos International Co., Inc. ....11

Linx Technologies .....39

Lynxmotion, Inc. ....81

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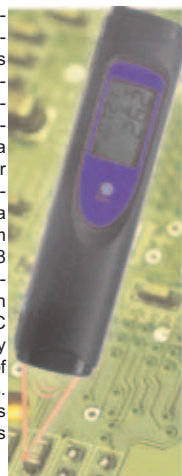
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